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MANUFACTURING METHODS AND TECHNOLOGY
(MANTECH) PROGRAM

FABRICATION AND DEMONSTRATION OF AN INTEGRALLY HEATED AND PRESSURIZED MOLD SYSTEM

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March 1981

FINAL REPORT

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The objectives of this research program are to reduce tooling costs for a composite tail rotor blade; reduce bond cure cycle time spans; and realize energy savings when compared to the conventional autoclave cure system. A thermally efficient mold bond insert and structure was designed and fabricated. Three bearingless tail rotor blades for a light helicopter were manufactured.

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PREFACE

This report describes the work accomplished by Bell Helicopter Textron under U.S. Army Contract DAAG46-79-C-0032, "Fabrication and Demonstration of an Integrally Heated and Pressurized Mold System."

The program was sponsored by the U.S. Army Aviation Research and Development Command, St. Louis, Missouri, through a contract with the Army Materials and Mechanics Research Center, Watertown, Massachusetts. The contract was administered by Contracting Officer Mr. Frank Sousa and conducted under the technical direction of Mr. Dana Granville. Contracted work began in June 1979 and was completed through process cost analysis in April 1980.

Technical tasks in this program were performed under the technical direction of BHT Project Engineer, Robert Anderson, assisted by Principal Investigator, John Goodwin. Technical reports were prepared by Jim Baker.

Acknowledgement is given also to Jan Cernosek, Jerry Peach, and the laboratory personnel who contributed to the successful completion of the project.

This project was accomplished as a part of the U.S. Army Aviation Research and Development Command Manufacturing Methods and Technology program with the primary objective to develop on a timely basis, manufacturing processes, techniques and equipment for use in the production of Army materiel. Comments are solicited on the potential use of the information presented as applied to present and future programs. Such comments should be sent to: U.S. Army Aviation Research and Development Command, Attention: DRDAV-EGX, 4300 Goodfellow Blvd., St. Louis, Missouri 63166.

TABLE OF CONTENTS

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TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

SUMMARY

A program was conducted to develop and demonstrate an integrally heated and pressurized mold system for curing composite rotor blades. The objective of the program was to reduce curing costs by reducing tooling costs and cure cycle time.

An analysis was made of four types of heating media and five mold configurations to develop the best overall system. The system adopted consisted of a water-heated mold with removable inserts.

Four bearingless tail rotor blades were fabricated and tested to demonstrate the system. In comparison with autoclave curing, the results indicated a 52 percent reduction in cycle time, 83 percent reduction in energy consumption, and substantial reductions in tooling costs.

The integrally heated and pressurized mold proved to be a viable alternative to autoclave curing and is directly applicable to the curing of all main and tail rotor blades with the potential to reduce costs significantly.

1. INTRODUCTION

Significant costs are associated with autoclave curing and bonding of helicopter rotor blades. Autoclave curing is comparatively slow, energy intensive and requires the use of vacuum bagging. Additionally, the tooling is costly, leaks are common, and there are quality consideration.

The objective of this program was to develop a new mold system which incorporated integral heating and pressurization to reduce curing costs by reducing tooling costs and cure cycle time. A system of this type would permit the use of inexpensive tooling while providing energy savings by utilizing an efficient thermal transfer technique.

This report describes the development and fabrication of such a mold system which was proven by the production and testing of four bearingless tail rotor blades. A cost analysis was then performed comparing the cost of blades produced by this system with autoclave curing and bonding.

2. BACKGROUND

Aircraft structural bonding first came into use in the 1940's with the use of rubber based adhesives. Along with the adhesives, the aircraft industry borrowed the technology of using vacuum bags and autoclaves for heating and pressurized curing. As adhesives and bonding became the state-of-the-art in aircraft, so did vacuum bagging and autoclaves. For almost three decades the equipment and methods used in bonding and curing did not dramatically change.

The need for better tool utilization, faster cure cycles, and the increasing cost of autoclaving led BHT to consider alternate technology. The first electrically heated, water cooled bonding press for metal tail rotor blades at BHT was installed in 1974.

Increasing quantity requirements for composite main rotor blades created new opportunities for breaking established patterns of bonding and curing. Fabrication concepts for composite blades favored cocuring and the use of processes other than autoclaves. The bond press developed for main blades was heated and cooled with pressurized water. The closing of the press and subsequent pressurizing was accomplished with a hydraulic water/oil emulsion system. The thirty-foot press for bonding and curing composite main rotor blades became operational in 1978.

In 1977, a BHT research program produced the first bearingless tail rotor blade. The technical success of that program, combined with the potential for broad application of the principles, made the blade a logical choice as a demonstration article for this program to develop an energy efficient, low cost integrally heated and pressurized mold.

3. PROGRAM PLAN

The program plan for fabricating and demonstrating an integrally heated and pressurized mold system consisted of five tasks. A description of these tasks is presented below:

3.1 TASK I - ARTICLE SELECTION

A composite main or tail rotor blade and/or assembly was to be selected as the demonstration article. The article produced would be a minimum of 75 percent of the full blade length.

3.2 TASK II - MOLD DESIGN AND MANUFACTURE

A self-contained mold system was to be designed and fabricated having integral heating, cooling and pressurization capabilities for curing the demonstration articles. The selection of materials was to be based on thermal and heat flow analysis for optimum cycle times and energy requirements. The mold system would be designed to cure a minimum of 1000 demonstration articles.

3.3 TASK III - FABRICATION OF DEMONSTRATION ARTICLES

A minimum of three demonstration articles of identical materials and configuration as found in the production or development rotor blade were to be fabricated and cured in the mold system. Detailed records of time, temperature and pressure for each cure cycle were to be kept.

3.4 TASK IV - QUALIFICATION TESTS

One of the demonstration articles would be subjected to the same qualification tests required of the production or development blade to verify its integrity after cure in the mold system. Two demonstration articles were to be delivered to the Army.

3.5 TASK V - COST ANALYSIS

A cost analysis would be prepared to determine the cost of curing 10, 100 and 1000 demonstration articles in the integrally heated and pressurized mold system as compared to using existing curing techniques. The analysis would included costs such as materials, labor, tooling, and energy.

3.6 FINAL REPORT

The final report would reflect all work accomplished under the contract. Detail descriptions would be included for the mold design, fabrication of demonstration articles, qualification and the cost analysis.

3.7 INDUSTRY BRIEFING

An industry briefing would be held to present the program in its entirety to the Army and industry with an Executive Summary made available at that time to briefly describe the program and the results.

4. RESULTS AND DISCUSSION

This program consisted of five tasks:

- Task I - Article selection
- Task II - Mold design and manufacture
- Task III - Fabrication of demonstration blades
- Task IV - Qualification of demonstration blades
- Task V - Cost analysis

4.1 TASK I - ARTICLE SELECTION

The contract required the demonstration article to be a composite main or tail rotor blade in current production or developmental status. The article produced would be a full chordwise section incorporating at least 75 percent of the blade's length with a minimum of 3 feet.

4.1.1 Candidate Components

Three blades were considered as demonstration articles. The candidates were the 214 and 412 main rotor blades and the 599-318-103 bearingless tail rotor. All of these blades met the criteria in that they were composites and either production or developmental products.

The main rotor blades were determined to be too costly for this project in tooling and materials. Both blades were 23 feet or over in length which would require a section at least 17 feet long for demonstration. In addition, the 412 blade was early in its production cycle and neither blade was immediately applicable to a military ship.

4.1.2 Bearingless Tail Rotor Selection

The bearingless tail rotor (Figure 4-1) was a developmental project with a half-span mold in existence which could be used as a full mold tracing pattern. The tip-to-tip length of an untrimmed tail rotor was 74 inches. Therefore, a full tail rotor could be molded at one time at a low tooling cost while incorporating an advanced heating and cooling technique. The technology appeared to be scaleable to any size blade. In addition, the bearingless tail rotor had been successfully test flown and had the potential for retrofit on the OH-58's in service (Figure 4-2).

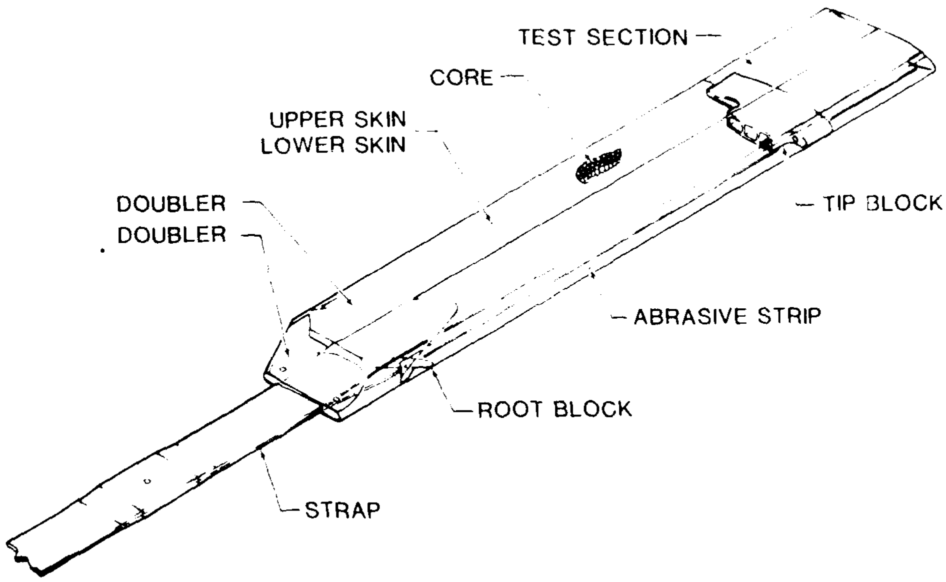


Figure 4-1. Bearingless Tail Rotor

Figure 4-2. OH-58 Helicopter.

4.2 TASK II - MOLD DESIGN AND MANUFACTURE

This task consisted of analyzing the different types of heating and cooling systems along with evaluating the various mold and restraint configurations. It was felt that substantial improvements in cycle time and energy consumption could be made over the conventional integrally heated and pressurized mold (Figure 4-3).

4.2.1 Heating and Cooling Design Analysis

Four methods of heating the mold were considered: steam, oil, electricity, and pressurized water.

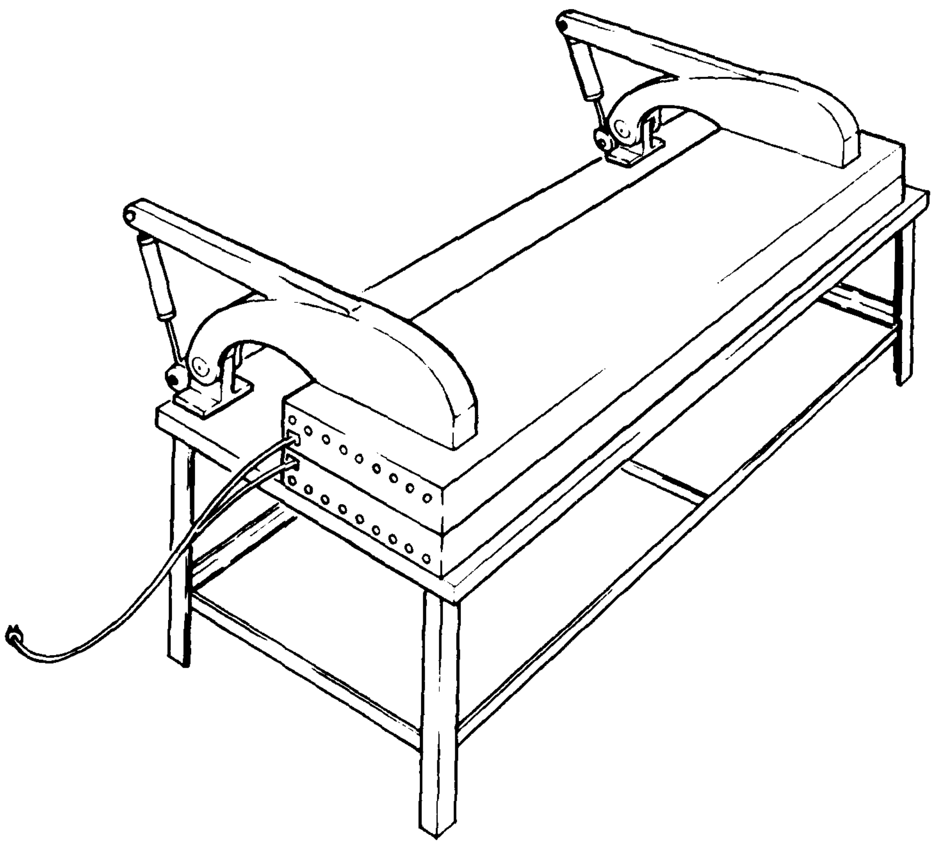


Figure 4-3. Conventional Concept - Integrally Heated and Pressurized Mold.

Steam is an excellent medium for transferring heat but has some drawbacks as follows:

- system requires conformance to boiler codes
- requires a licensed operator
- rigid safety requirements necessary
- corrosion

Oil is also a good heat transfer medium but offers some serious problems as noted:

- a high contaminate in a bonding environment. Oil systems are almost impossible to seal off, allowing oil contamination of most surfaces through direct and airborne means.
- substantial storage capacity is required along with a heating system and hydraulic pumps.
- a high maintenance system.
- expensive.

Electric heating eliminates the need for a transfer medium and the system is relatively simple to fabricate. However, the following constraints inhibit its selection for use in large bonding installations:

- expensive to set up due to multiple elements and controls.
- heater burn-out is frequent and expensive to replace.
- heating tends to be localized and nonuniform.
- dangerous when used in conjunction with water cooling.

Pressurized water is an excellent heating and cooling medium which can be circulated through a closed system. It provides uniform heating and cooling, is inexpensive to supply, is clean and is low in maintenance. Installation costs are relatively low when compared to the other systems. When all considerations were complete, electricity and pressurized water were the heat medium choices for the candidate mold systems.

4.2.2 Mold Closing Mechanisms

Four types of mold closing mechanisms were studied for cost, speed, and ease of operation.

A mechanical closing mechanism composed of gears and/or chains and levers is quite simple and inexpensive to build with minimum maintenance requirements. A mechanism of this type, however, is usually slow and lacks the compliance sometimes needed during mold closing.

Hydraulic cylinders are the most popular method of mold closing due to their speed and operational ease. They are expensive to install and maintain along with being a possible contaminate in a bonding environment.

Pneumatic cylinders are also popular and have speed and operational ease. They are noncontaminating but are expensive to install and maintain.

The most promising method evaluated was a pneumatic inflatable tube concept that could be fabricated from double jacketed fire hoses, pressurized with air and the circumferential expansion used to actuate the mold platen (Ref. Figure 4-19). The mechanism would be inexpensive to fabricate and maintain and be noncontaminating. Advantages in cost, simplicity and effectiveness made this concept a logical choice for the mold closing mechanism.

4.2.3 Mold Configuration Evaluation

Five different concepts in mold configuration were evaluated for efficiency of heat transfer, energy consumption, ease of operation, and simplicity of manufacture.

4.2.3.1 Electrically Heated and Water Cooled Sculptured Steel Mold. A mold of this type, as shown in Figure 4-4, is efficient in heat transfer, but has inherent fabrication and operational disadvantages. Drilling of ports for heaters and cooling fluid makes the mold expensive to manufacture. Furthermore, this configuration requires a large platen (2895 pounds) to accommodate the ported volume and still retain structural integrity. The consequence of a large mass is high energy consumption and an extended cure cycle time. Operational problems arise as heat rods break down and cause local overheating. Maintenance and repair costs for this configuration would be high. Safety hazards resulting from high voltage and water in close proximity were also considered.

4.2.3.2 Water Heated and Cooled Sculptured Steel Mold. Figure 4-5 illustrates a mold that is also efficient in heat transfer and has definite advantages over an electrically heated system. The single port, sculptured mold has fewer components, is more reliable, and provides uniform heating.

This system shares several undesirable features with the electrically heated unit, such as a large mass (1716 pounds) and both are costly to machine.

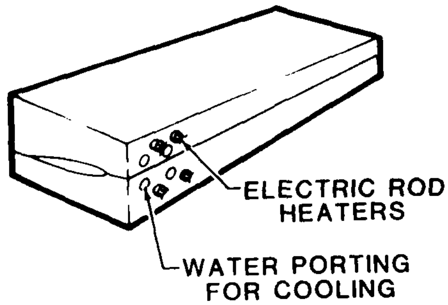


Figure 4-4. Sculptured and Ported Mold Halves with Electric Heaters and Water Cooling.

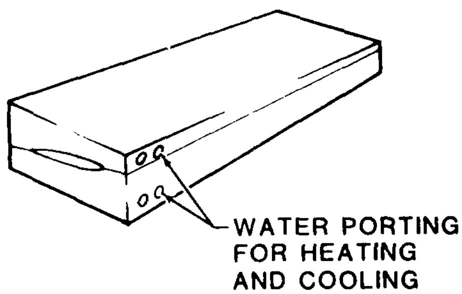


Figure 4-5. Sculptured and Ported Mold Halves for Water Heating and Cooling.

4.2.3.3 Electrically Heated and Water Cooled Steel Platens with Removable Sculptured Inserts. The configuration shown in Figure 4-6, introduces an element of versatility not possible with the drilled, ported and sculptured mold described in 4.2.3.1. The shape of the part to be cured is sculptured into thin removable inserts. Thermal gains can be realized by fabricating the inserts from aluminum.

It should be noted that calculations were made to explore the feasibility of curing the fiberglass tail rotor in aluminum inserts. It was determined the thermal expansion differences would occur in directions and amounts that would not adversely affect the operation.

The normal disadvantages of electrical systems, such as non-uniform heating and high maintenance costs still exist with this configuration. Total mass for the mold system platens would be 2361 pounds.

4.2.3.4 Water Heated and Cooled Steel Platens with Removable Sculptured Inserts. The system shown in Figure 4-7 incorporates removable inserts with the advantages of light weight, lower cost, uniform heating, versatility, and the reliability of a single port heating and cooling system. The use of aluminum inserts reduces the sum of the upper and lower platen mass to 1357 pounds.

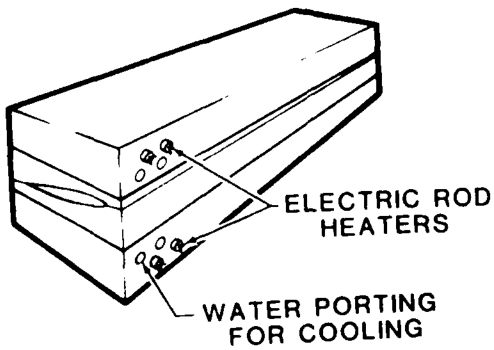


Figure 4-6. Sculptured Mold Inserts and Ported Platens with Electric Heaters and Water Cooling.

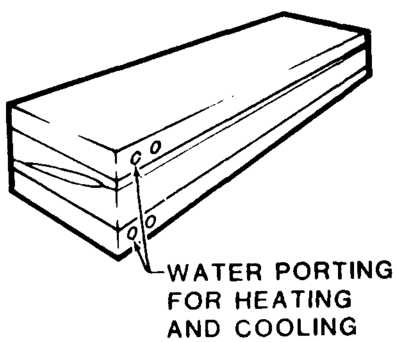


Figure 4-7. Sculptured Mold Inserts and Ported Platens for Water Heating and Cooling.

4.2.3.5 Panel Coil With Removable Sculptured Inserts. The fifth candidate mold design (Figure 4-8) features a low mass panel coil heat exchange unit (Figure 4-9) used in conjunction with the sculptured aluminum insert concept. Water is used for the heating and cooling medium.

Each platen assembly is comprised of a structural steel back-up plate, a transite insulating plate and a steel panel coil with passages to permit high volume flow of hot or cold water. This system is less massive than the other design considerations and has excellent thermal transfer. An aluminum face plate is used between the panel coil and mold insert to distribute any point loads that might damage the coil face.

The removable inserts, as discussed previously, afford good heat transfer, light weight, and easier fabrication. When they are combined with the panel coils, the result is a relatively low cost, energy efficient system.

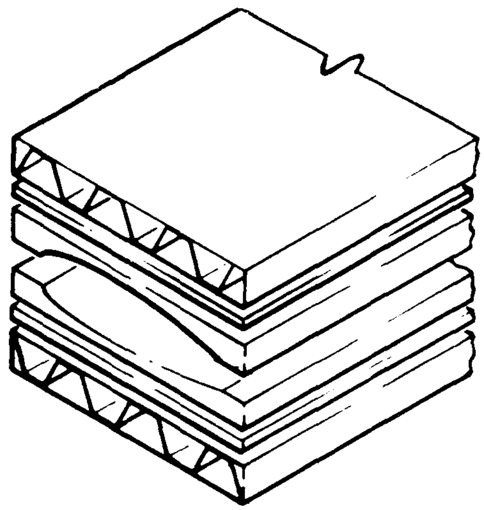


Figure 4-8. Panel Coil and Sculptured Insert Construction with Water Heating and Cooling.

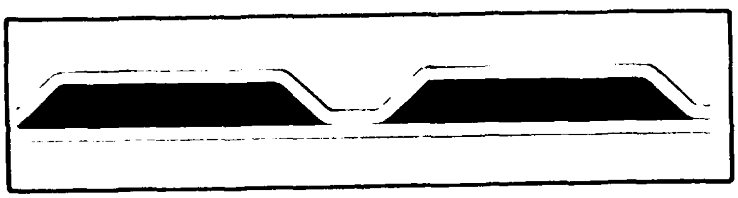


Figure 4-9. Cross Section of Panel Coil

4.2.4 Mold Energy Requirement Analysis

All five mold configurations evaluated in 4.2.3 were subjected to an analysis of their energy requirements. Table 4-1 indicates the *reference data* used in the formulas (Table 4-2) to calculate the energy consumption for a cured bearingless tail rotor blade. A typical calculation is shown in Table 4-3, and complete calculations for all five configurations can be found in Appendix A.

Table 4-1. Reference Data.

- WT WATER - 8.34 LBS/GAL
- WATER FLOW - 10.2 GAL/MIN
- WT OF 10.2 GAL WATER - 85.068 LBS
- SURFACE HEAT LOSS STEEL - 180 WATTS/SQ FT/HOUR
- SURFACE HEAT LOSS ALUMINUM - 90 WATTS/SQ FT/HOUR
- SPECIFIC HEAT

  STEEL - .120

  AL AL - .230

  GLASS - .197

  WATER - 1.000
- HP ELECTRIC MOTORS ON PUMPS

  $$\frac{\text{PSI X GPM}}{1714} = \text{HP}$$

  1 HP = 745.7 WATTS

Table 4-2. Formulas for Calculating Energy Requirements.

For Initial Heat Up: KWH

$$\frac{\text{Weight of Material (in pounds)} \times \text{Specific Heat (BTU's per pound -}^{\circ}\text{F)} \times \text{Temperature Differential (final less initial -}^{\circ}\text{F)}}{\text{3412 (BTU's per kilowatt hour)}}$$

For Heat Losses: KWH

$$\frac{\text{Exposed Area (square feet)} \times \text{Heat loss at temperature (watts per square foot)} \times \text{Working cycle time (hours)}}{\text{1000 (watts per kilowatt)}}$$

Table 4-3. Typical Energy Calculation

A. POWER REQUIREMENT FOR INITIAL HEAT-UP ESTIMATED

1. Heat absorbed by: INTEGRAL STEEL MOLD - ELECT. HT./WATER COOLED

Weight of Material (Lb) x Specific Heat (BTU/Lb-F) x Temp. Dif. (Final-Initial) (F) / 3412(BTU/KWH) x (Time in Hours)				KWH

2. Heat absorbed by: STEEL MOLD

2892 LBS x .12 x 200°F x 30 MIN. / 3412 x .5 — 40.68 KWH

3. Heat absorbed by: TAIL ROTOR BLADE

3.4 LBS x .197 x 200°F x 30 MIN / 3412 x .5 — .08 KWH

4. Heat absorbed by: WATER

85.068 LBS. x 1.0 x 200°F x 30 MIN / 3412 x .5 — 9.97 KWH

5. Heat absorbed by: ____________

____ x ____ x ____ / 3412 — ____ KWH

6. Heat absorbed by: ____________

____ x ____ x ____ — ____ KWH

Total Heat Requirement for Initial Heat-up: ____ ____ KWH

Total Power Requirement for Initial Heat-up: ____ 50.73 KWH

B. POWER REQUIREMENT FOR OPERATING HEAT

1. Heat Required to Replace Heat Losses: ____________

(Exposed Surf. Area) (sq. ft) x (Heat Loss at Final Oper. Temp) (W/sq ft) x (Cycle Time) Hrs) / 1000 (W/KW) — ____ KWH

2. Heat Required to Replace Heat Losses: STEEL MOLD

19.01 Sq. Ft. x 180 WATTS/Sq. Ft. x 1 HR / 1000 — 3.42 KWH

3. Heat Required to Replace Heat Losses: ____________

____ / 1000 — ____ KWH

4. Heat Required to Replace Heat Losses: ____________

____ / 1000 — ____ KWH

Circulation Pump: 3.0 KWH

Total Energy Use 57.15 KWH

The calculated energy consumption for the integral sculptured and ported steel molds (Figures 4-10 and 4-11) was 57.15 kwh for electric heating and 39.62 kwh for water heating. The 44 percent difference in consumption is due to the extra mass required for separate electric heating and water cooling ports.

The aluminum inserted steel platen mold systems (Figure 4-12 and 4-13) were calculated at 50.12 kwh energy consumption for electric heating and 35.67 kwh for water heating. The 41 percent difference in consumption again is due to mass difference.

The most energy conserving system was the water heated steel panel coil with aluminum inserts (Figure 4-14). The calculated energy consumption was a low 23.62 kwh per cure cycle. A substantial mass reduction contributed by the panel coil plus its high heating capacity and thin walls enabled the system to transfer easily a large amount of the heat contained in the water to the inserts.

Figure 4-15 compares the calculated energy consumption for each of the five mold design candidates. It clearly illustrates why the panel coil approach was chosen for the MM&T mold system.

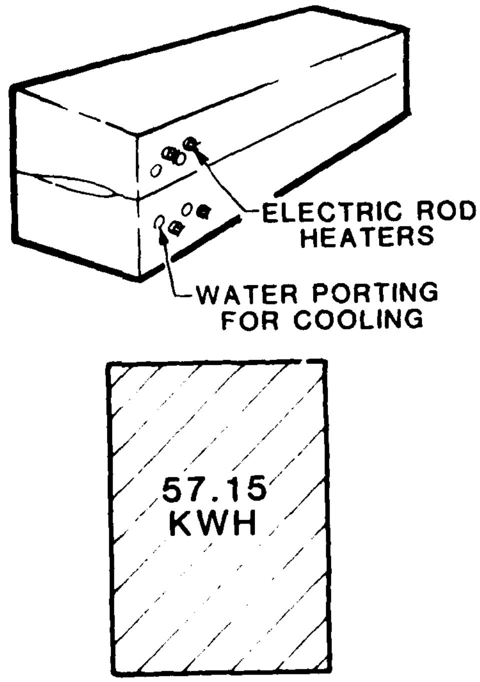


Figure 4-10. Energy Consumption - Sculptured and Ported Steel Mold Halves with Electric Heaters and Water Cooling.

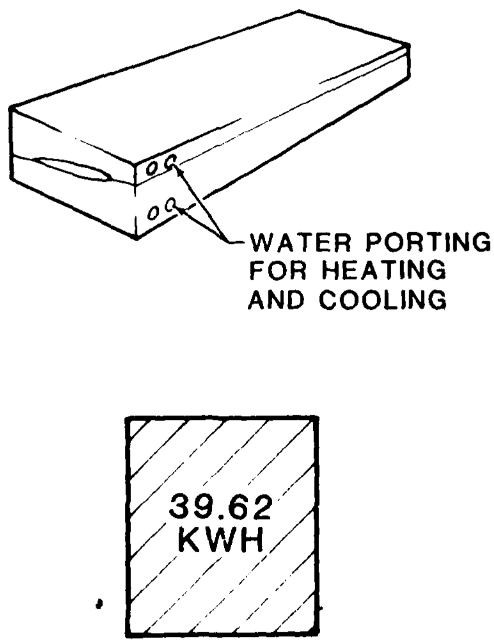
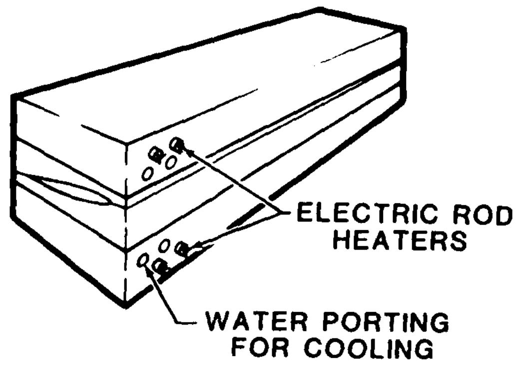


Figure 4-11. Energy Consumption - Sculptured and Ported Steel Mold Halves with Water Heating and Cooling.



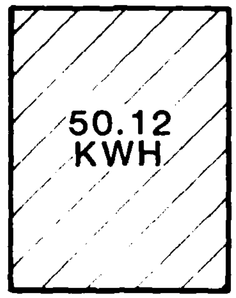
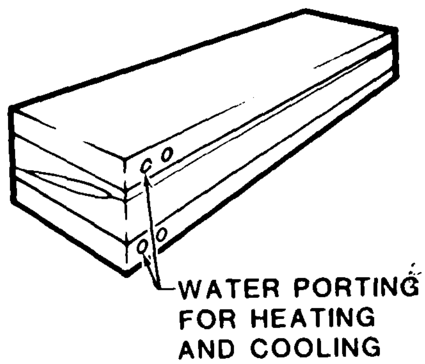


Figure 4-12. Energy Consumption - Sculptured Aluminum Inserts and Ported Steel Platens with Electric Heating and Water Cooling.



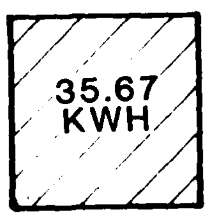


Figure 4-13. Energy Consumption - Sculptured Aluminum Inserts and Ported Steel Platens with Water Heating and Cooling.

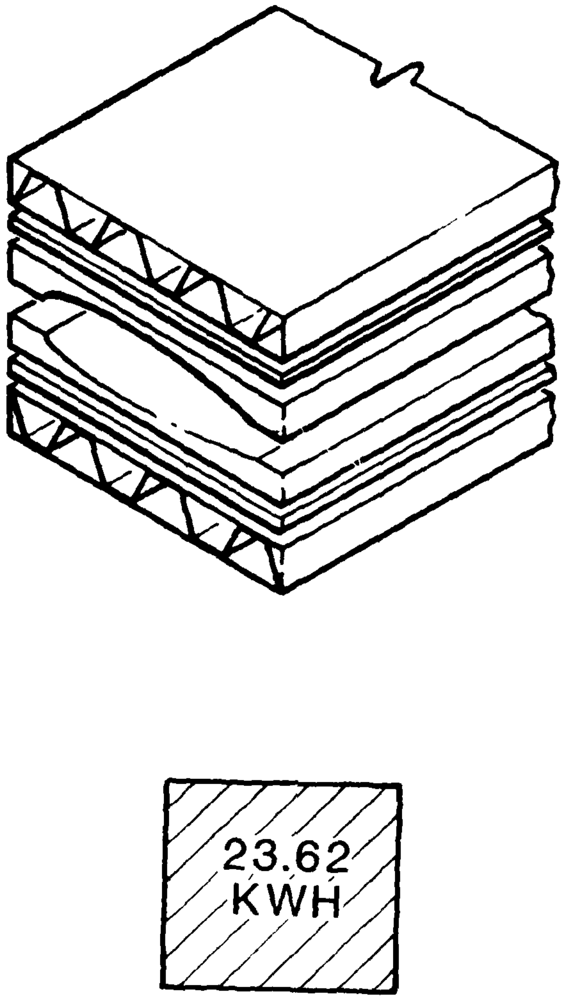


Figure 4-14. Energy Consumption - Sculptured Aluminum Inserts and Panel Coil Construction with Water Heating and Cooling. (MM&T Mold)

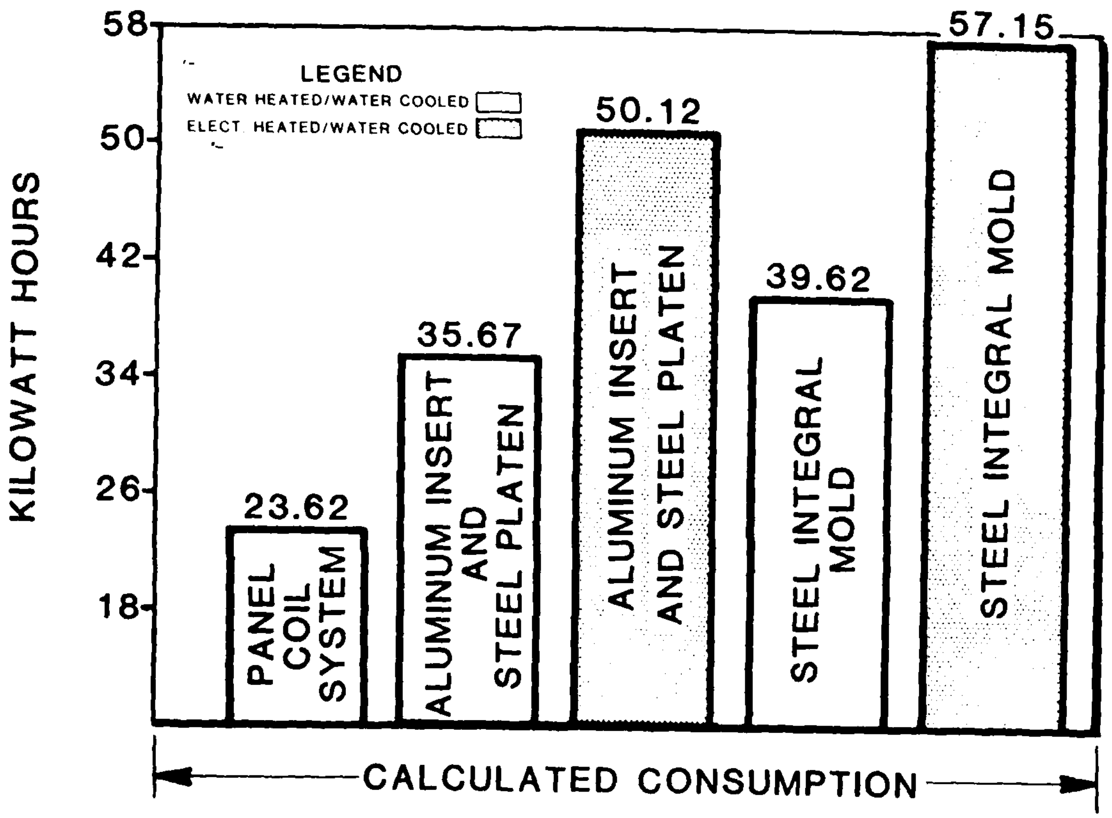


Figure 4-15. Comparison of Calculated Energy Consumption for Five Mold Design Candidates.

4.2.5 Design and Fabrication of Mold

The mold was designed in two parts consisting of a panel coil restraining system and removable inserts. This versatile design enables inserts with other molded shapes to be made for the same restraint system.

The mold system design is presented in Appendix B.

4.2.5.1 Mold Restraining Structure. The restraining structure consisted of two 1/2-inch vertical steel plates bolted to 3/8-inch wall tubular steel top members and a 1/2-inch steel base plate. The upper platen was composed of a 1/2-inch steel back-up plate and a steel panel coil. A 1-inch thick sheet of transite was used for thermal insulation between the structural back-up plate and panel coil.

The platen assembly was completed with a 3/8-inch aluminum face plate to provide point load protection for the coil and act as a thermal conductor between the panel coil and the insert. Grooves were milled into the face plate to accept the weld beads on the panel coil as shown in Figure 4-16. Thermal conductivity was enhanced by using an aluminum-filled epoxy between the aluminum and panel coil. The entire upper platen was bolted together and held stationary by steel support brackets. Figures 4-17 and 4-18 show the structure including the top and bottom platens prior to installation of panel coils.

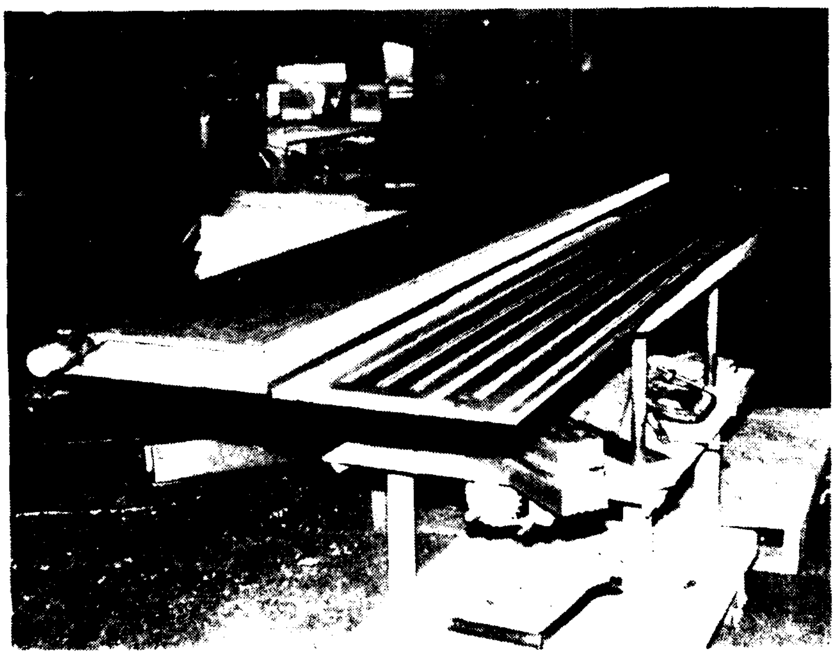


Figure 4-16. Panel Coil with Aluminum Face Plate Milled to Accept Weld Beads.

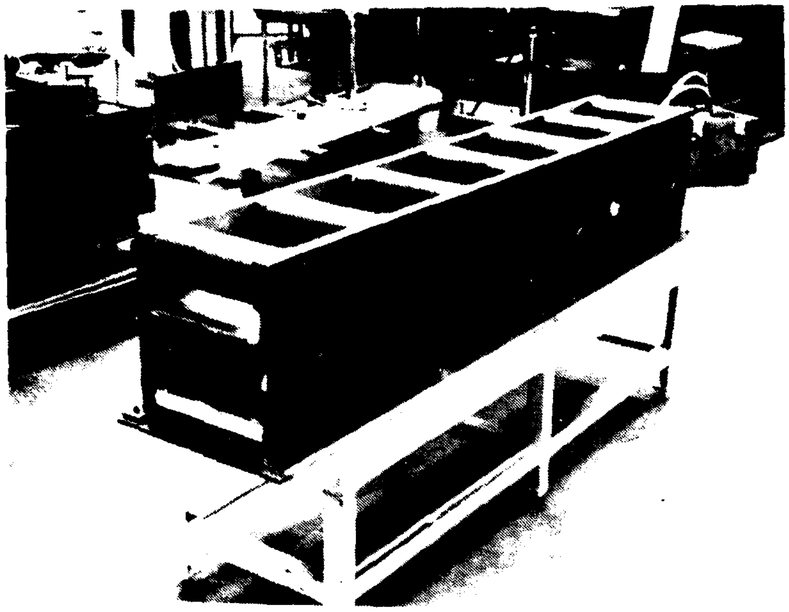


Figure 4-17. Mold Restraint Structure with Viewing Ports.

Figure 4-18. Mold Restraint Structure - End View.

The lower platen was fabricated in the same way except that it was not held stationary but floated on two 3-inch double-jacketed fire hoses. A cut-away view is shown in Figure 4-19.

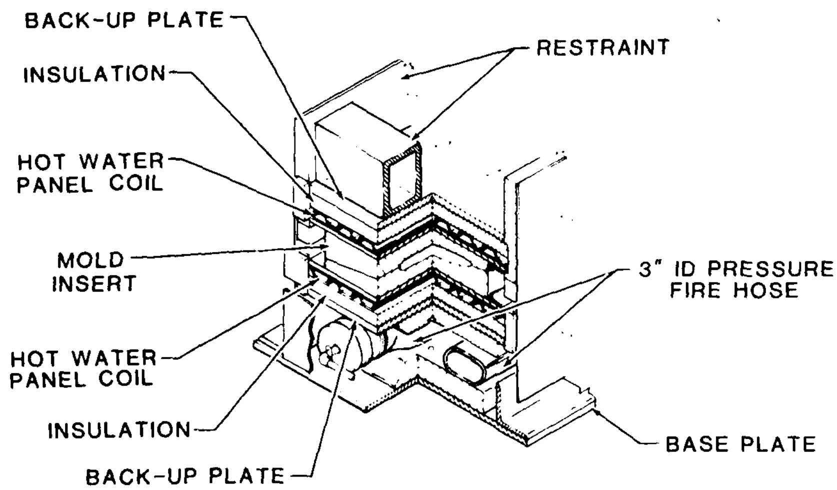


Figure 4-19. Cutaway View.

4.2.5.2 Insert Design and Fabrication. The inserts were fabricated from 6061-T6 aluminum. Studies described in 4.2.3.3 established that the differences in thermal expansion between the blade and inserts during cure would not produce unacceptable results.

A half-span mold (Figure 4-20) from the previous bearingless tail rotor research program was used as a tracing pattern for sculpturing the aluminum inserts. The pattern was shimmed at an 8° angle (Figure 4-21) so that the ±8° twist could be machined into the tool. Figures 4-22 and 4-23 show the rough and finish machining of the upper insert.

Grooves for matching keys were milled into the inserts (Figure 4-24) to ensure positive alignment upon closing.

The combined outside dimensions of the inserts were 8.8 inches wide x 2.7 inches high x 83 inches long. They weighed 178 pounds.

4.2.5.3 Mold Installation. The mold structure was placed adjacent to the BHT blade bonding press. The top platen inlet of the panel coil was connected into the water line from the bonding press. A line was then connected from the outlet of the top platen to the inlet of the bottom platen and then returned from the bottom platen outlet to the bonding press.

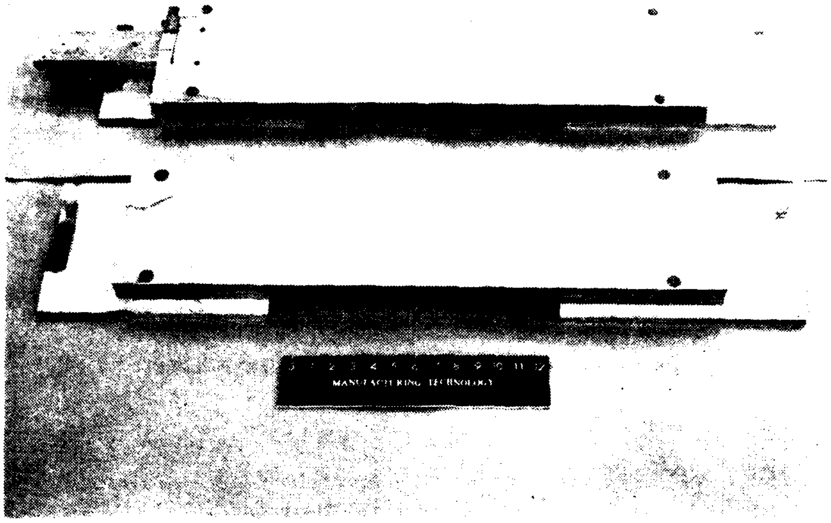


Figure 4-20. Half-span Research Blade Mold Used as Tracing Pattern.

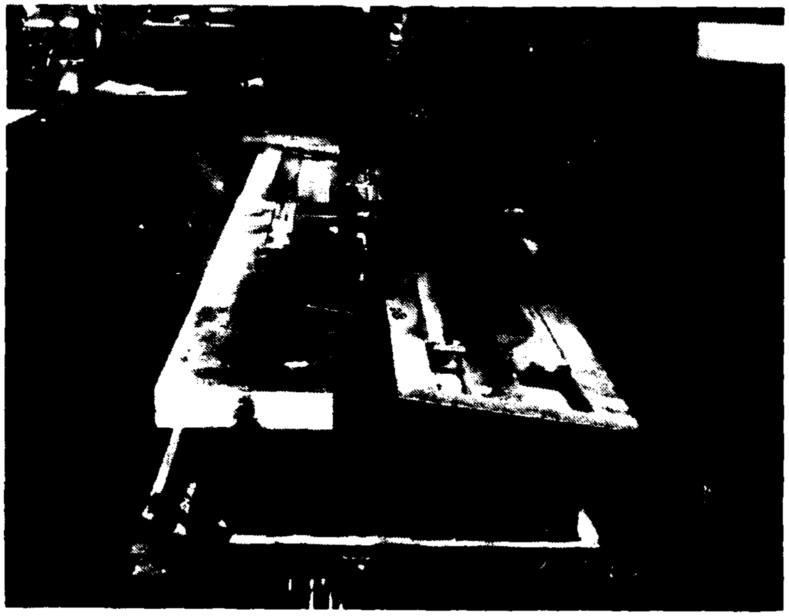


Figure 4-21. Tracing Pattern Right Foreground Mounted at 8° Angle.

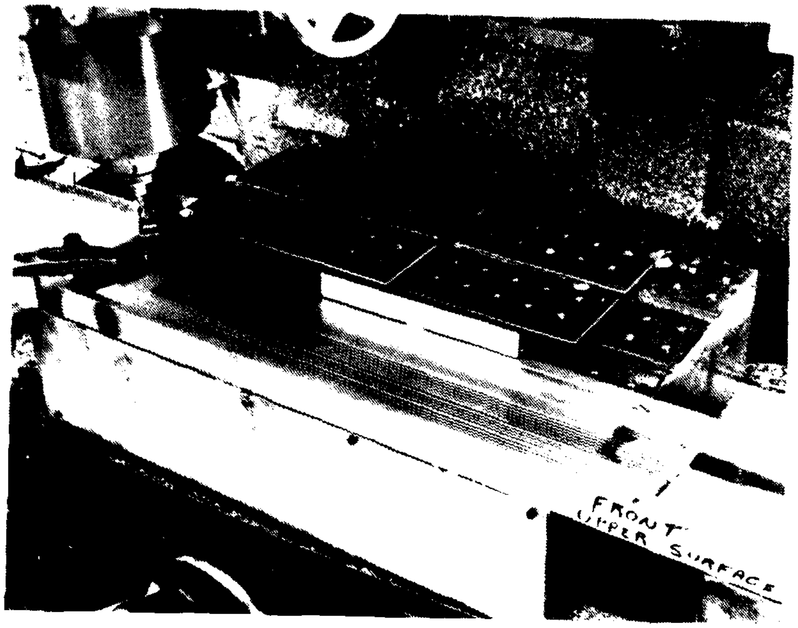


Figure 4-22. Rough Cut on Upper Insert Half.

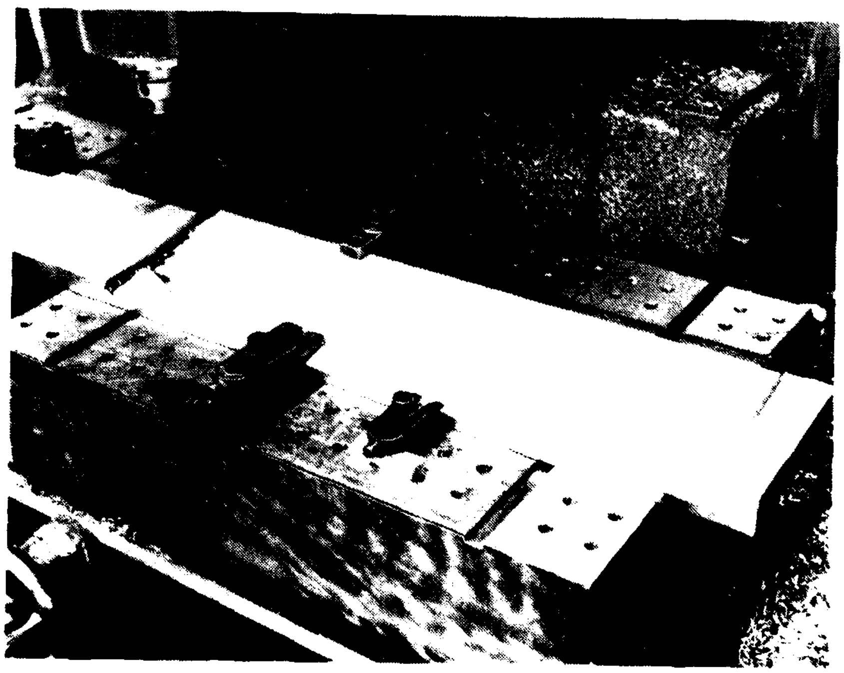


Figure 4-23. Completed Sculptured Area.

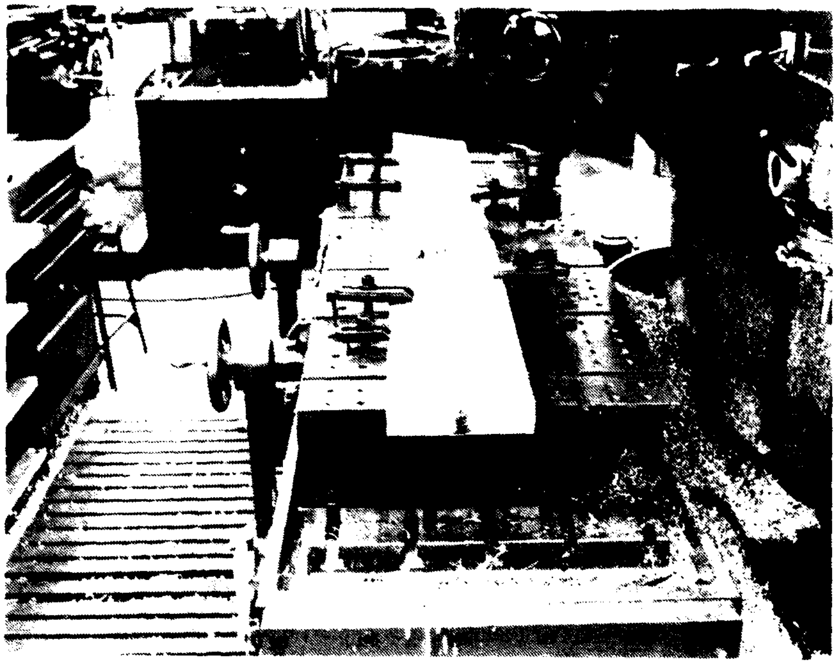


Figure 4-24. Milling Hub Area on Finished Upper Insert.

Figure 4-25 shows the schematic layout of the presses. Water is circulated through a closed loop containing a hot water generator and heat exchanger (Figure 4-26), attaining a temperature of 400°F and 400 psi. When cooling is required, chilled tower water is circulated through the heat exchanger thereby cooling the closed loop water.

Thermocouples were installed on both the supply and return lines along with a flowmeter (Figure 4-27) on the return line. The readings from these instruments were used in calculating the actual energy usage and to monitor the water temperature.

Safety precautions were taken due to the potential danger of a hot water system. All hot water lines were insulated and wrapped (Figure 4-28). The flowmeter and air pressure regulator were mounted on the wall (Figure 4-29) away from the mold structure. A plywood partition was erected between the mold and operator area as a precautionary measure. The maximum pressure ratings were obtained for all major components and are listed in Appendix C.

4.2.5.4 Mold Systems Operation Test. An aluminum block, approximately equal in volume to the mold inserts, was placed between the platens and subjected to a simulated cure cycle to verify that all mold functions were operating properly.

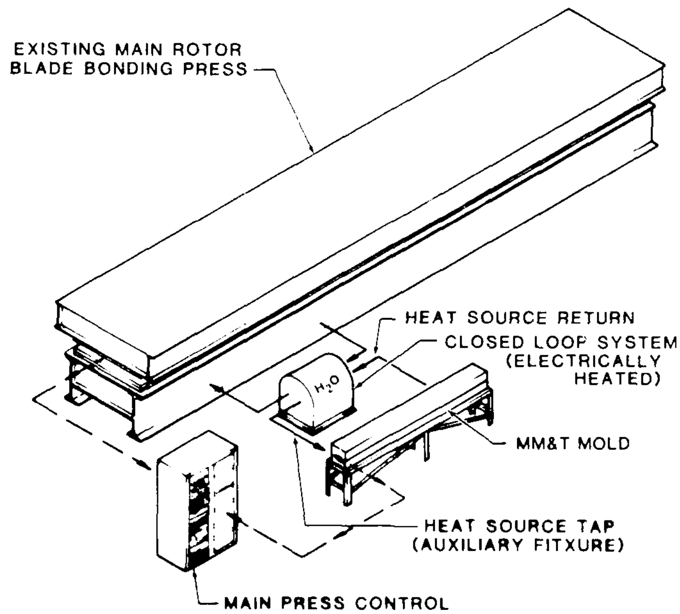


Figure 4-25. Schematic Layout of Presses.

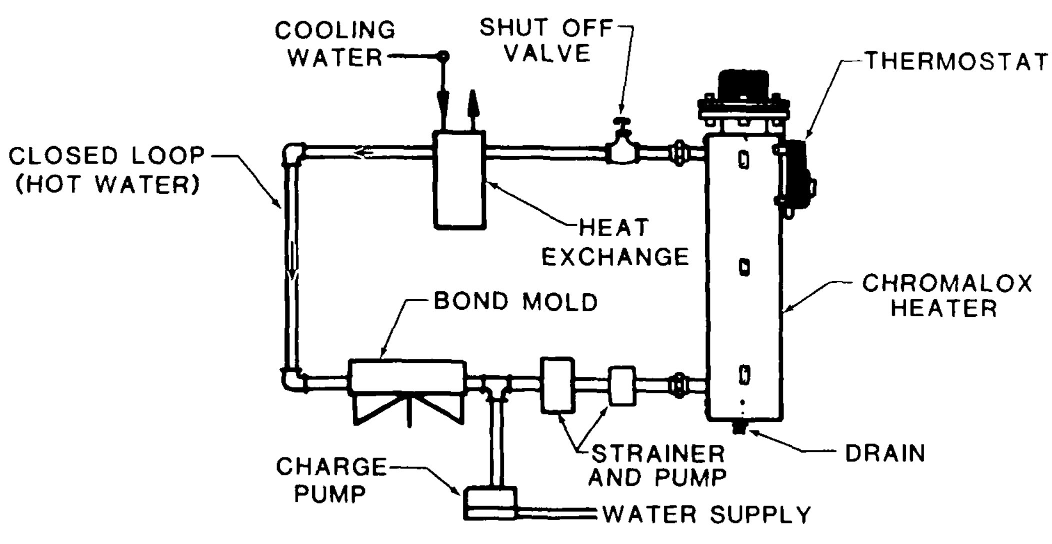


Figure 4-26. Hot Water Generator.

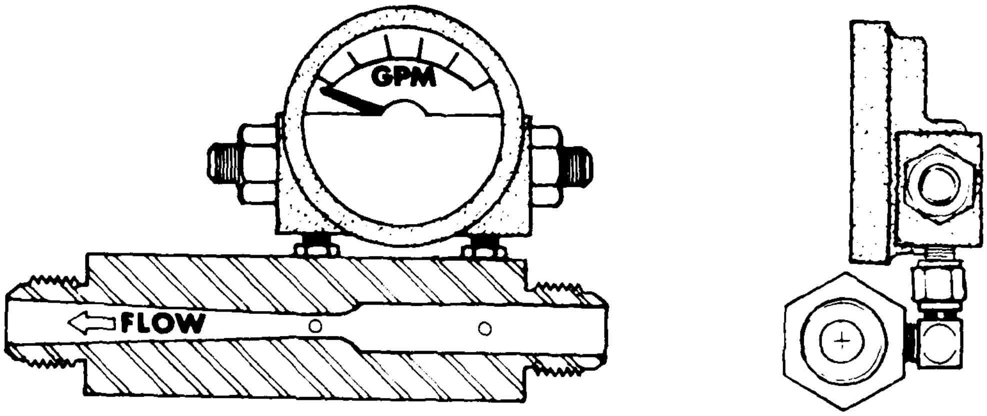


Figure 4-27. Hot Water Flowmeter Design.

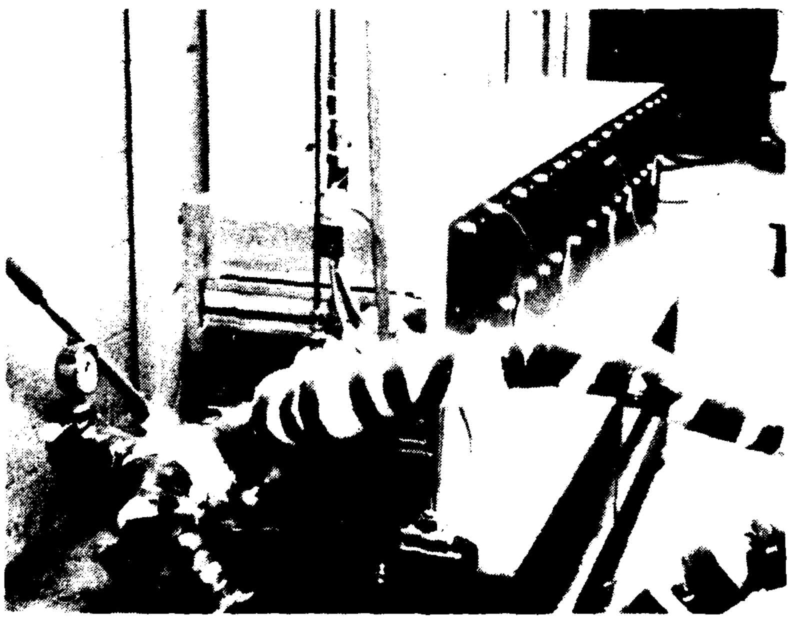


Figure 4-28. Installed Mold Restraint System with Insulated and Wrapped Hot Water Lines.

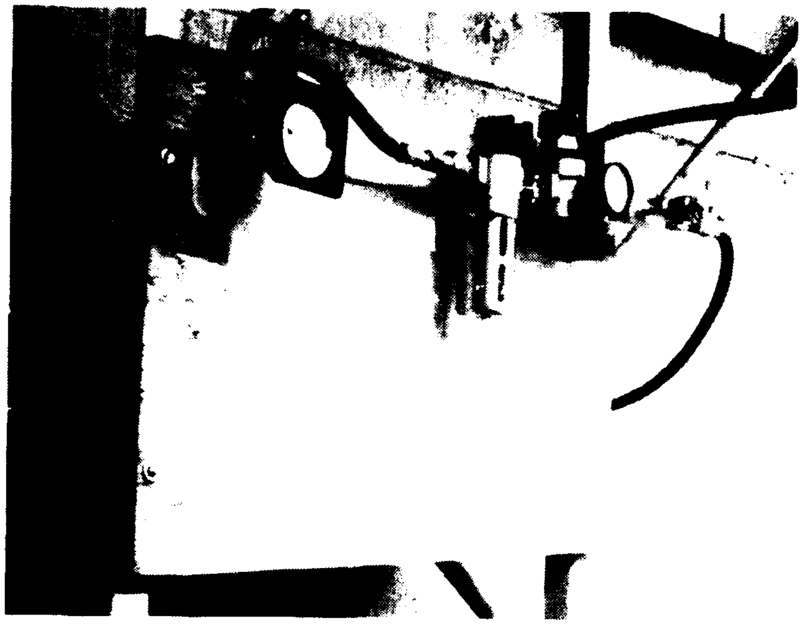


Figure 4-29. Flowmeter and Air Pressure Regulator Mounting.

Four thermocouples continuously recorded the temperatures during the ninety-minute test (Figure 4-30). The insert shows the location and number of thermocouples that can be traced by following the small stamped numbers on the chart.

The water inlet thermocouple, TC7, did not appear clearly on the strip chart and has been enhanced. The 10°F difference between the inlet and outlet water temperature indicates that the panel coil system distributes the heat uniformly even with a large heat sink.

The following observations were made:

- Water flow rate: 10.2 gallons per minute
- Temperature rise: 90°F to 270°F in 24 minutes
- Heat up rate: 7.5°F per minute
- Total time of test from 90°F: 83 minutes

The system test indicated all functions to be operating properly, and that the unit was ready to begin bonding blade assemblies.

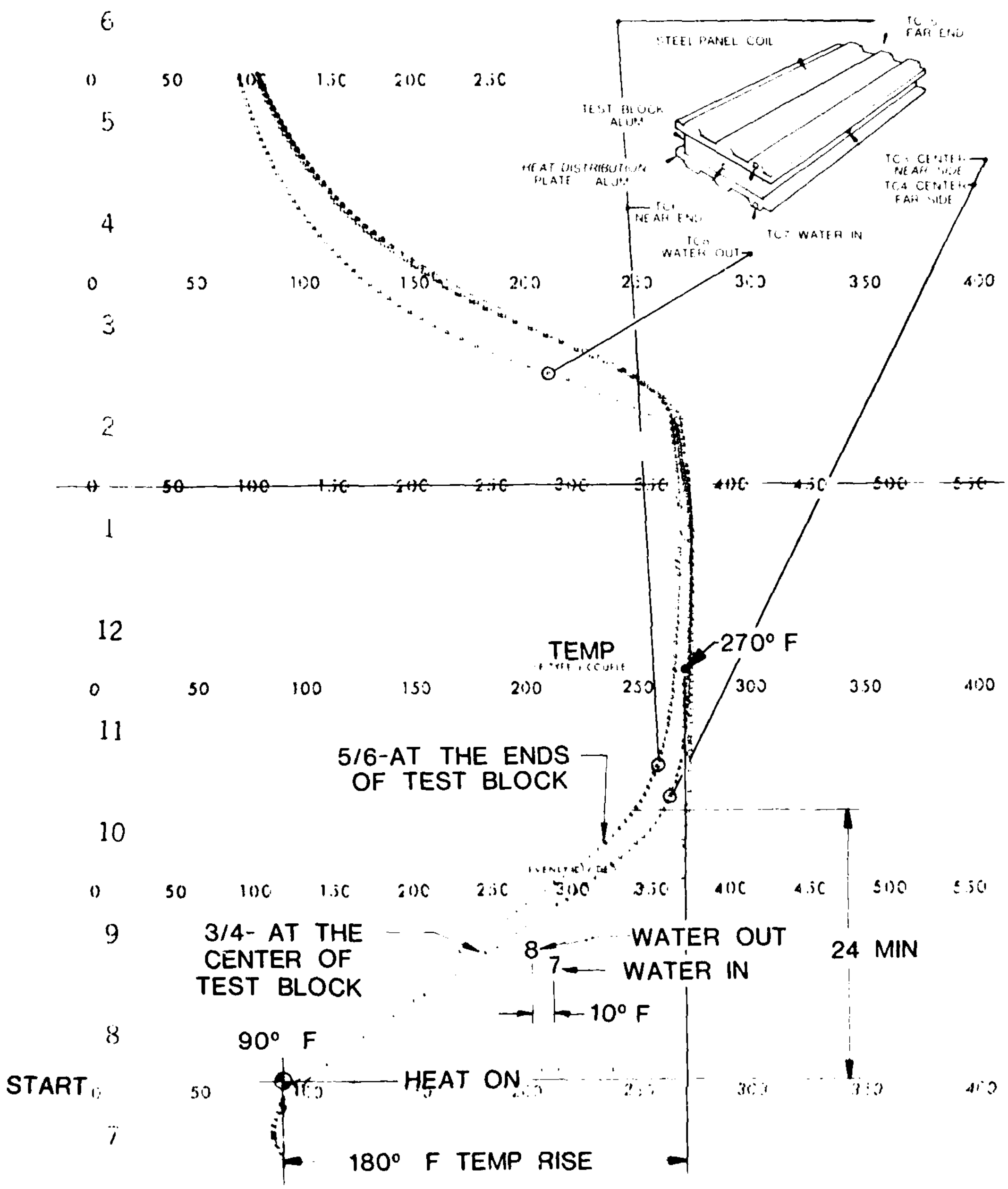


Figure 4-30. Temperature Profile of Mold Performance Test.

4.3 TASK III - FABRICATION OF DEMONSTRATION BLADES

4.3.1 Comparison to Research Blades

It is recognized that in an optimized production environment only the spar of the bearingless blade would be precured. All other assembly would be accomplished in a single cocure operation that would include simultaneous curing of the skins and bonding to the honeycomb. Since the thrust of this program was the development of an advanced mold system, establishing a manufacturing procedure was considered secondary. Therefore, the decision was made to produce the MM&T demonstration blades by the same procedure used for the 1977 research units. In this way the test values from both programs could be directly compared.

The blade design was not altered from the 1977 research program. In both programs the upper and lower blade skins were autoclave precured and the spar strap was press cured. The main difference in fabrication between the programs was the use of a full-span mold in this program to assemble both ends of the blade in the same bond sequence.

4.3.2 Blade Detail Fabrication

The spar strap layup ranged from 28 plys of epoxy preimpregnated unidirectional glass roving in the hub, to two plies at the tips. Both ends of the strap are canted 8° to build twist into the blade. The spar strap was then placed in a production bonding press and cured for 90 minutes at 265°F. Figure 4-31 shows a partial spar strap cured and trimmed.

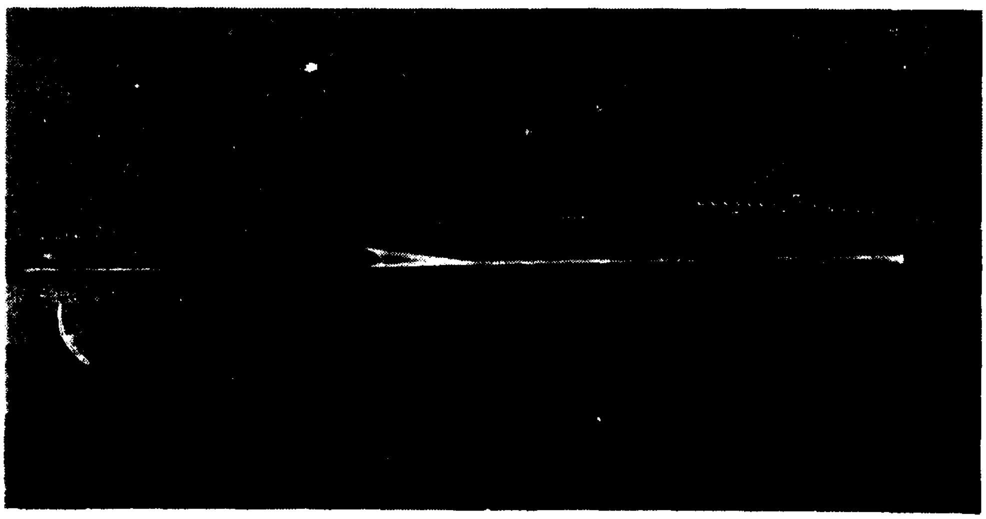


Figure 4-31. Edge View of Spar Strap Section.

The mold inserts were used to layup and precure the blade skins. Dummy doublers and abrasion strips were installed in the inserts (Figure 4-32) to create setbacks in the skins for bonding these details in the next assembly. Layup of the skin plies is shown in Figure 4-33. The left side shows one ply of 120 fiberglass cloth and the right one ply each of 120 and 181 fiberglass cloth. Root end reinforcements were laid at thirty-degree angles and a one-quarter inch wide reinforcement ply was laid along the trailing edge (Figure 4-34).

Two layers of peel ply were applied for bond line protection and to absorb excess resin flow (Figure 4-35). The second ply was stripped away after the cure cycle.

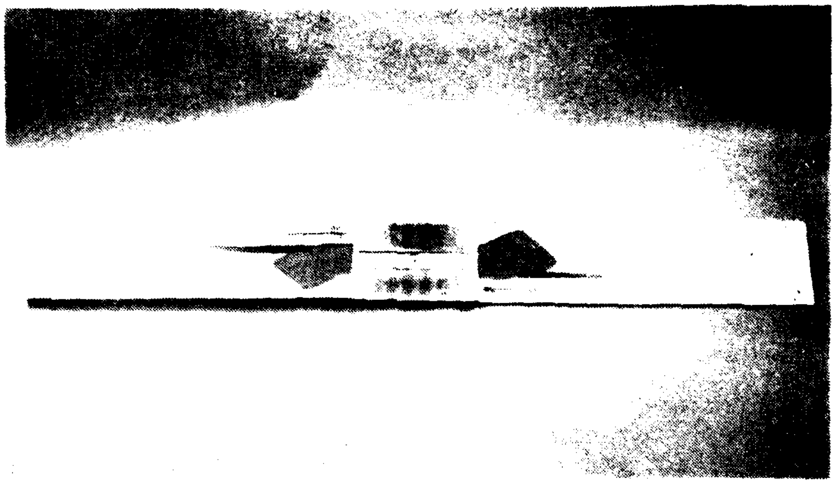


Figure 4-32. Mold with Dummy Doublers at Blade Root and Dummy Abrasion Strip.

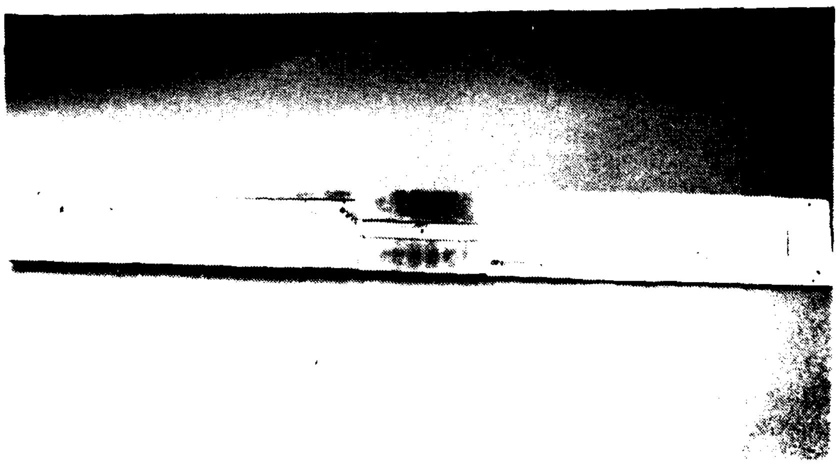


Figure 4-33. Skin Layup.

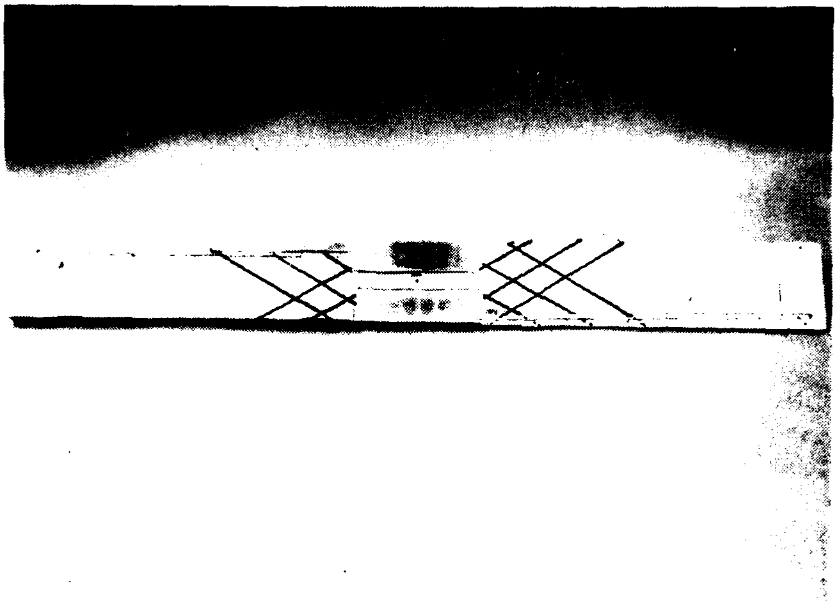


Figure 4-34. Thirty Degree Unidirectional Fiberglass Reinforcement at Blade Root.

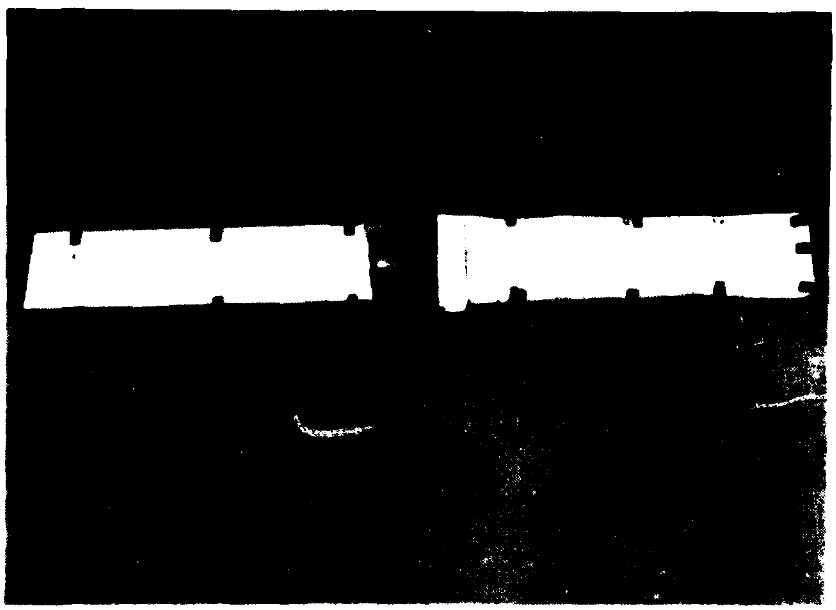


Figure 4-35. Application of Peel Plies to Bond Surfaces.

The skin set was prepared for autoclaving by wrapping with fiberglass cloth wicking, bagging and sealing (Figures 4-36 and 4-37). Autoclave vacuum lines where then attached and the skins were placed in the autoclave for a 90-minute cure at 265°F and 40 psi (Figure 4-38).

Figure 4-36. Heavy Weave Wicking Cloth Wrap Prior to Bagging.

Figure 4-37. Skins Bagged for Autoclave Cure.

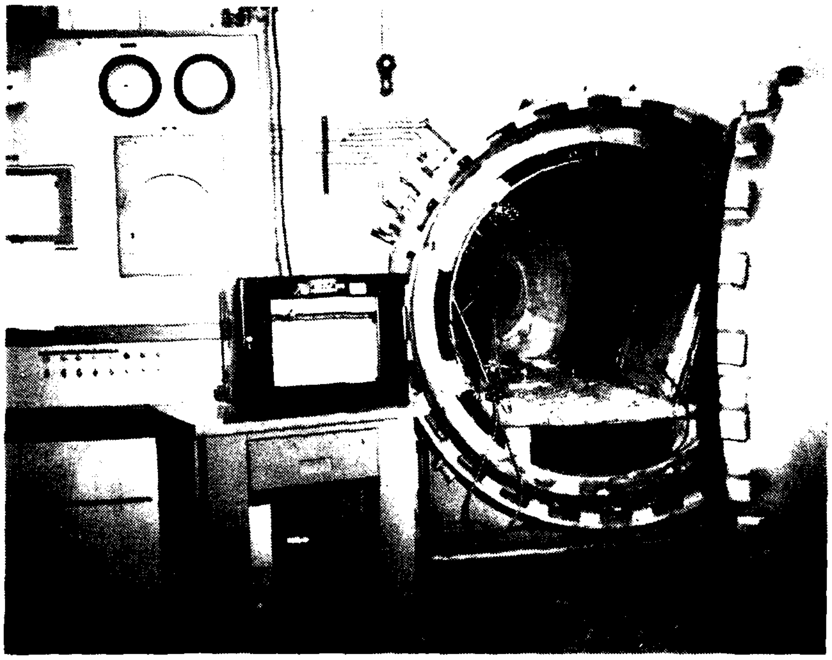


Figure 4-38. Autoclave Cure of Skins.

Figure 4-39, shows the skin set prior to trimming. One layer of peel ply is retained for protection.

The root blocks were formed in place by casting epoxy tooling resin into and around the yoke of the spar using the spar tool as a mold. The resin, Epocast 31-D with #9216 hardener, contained 5 percent (by weight) chopped glass fiber and was cured for 24 hours at room temperature.

The tip blocks were machined from solid blocks of fiber reinforced phenolic (Figure 4-40), then drilled, cleaned, baked and primed.

Aluminum doublers were cut to size, trimmed, anodized, and then primed with 2271-A for bonding.

Figure 4-39. Cured Skin Set Prior to Trimming.

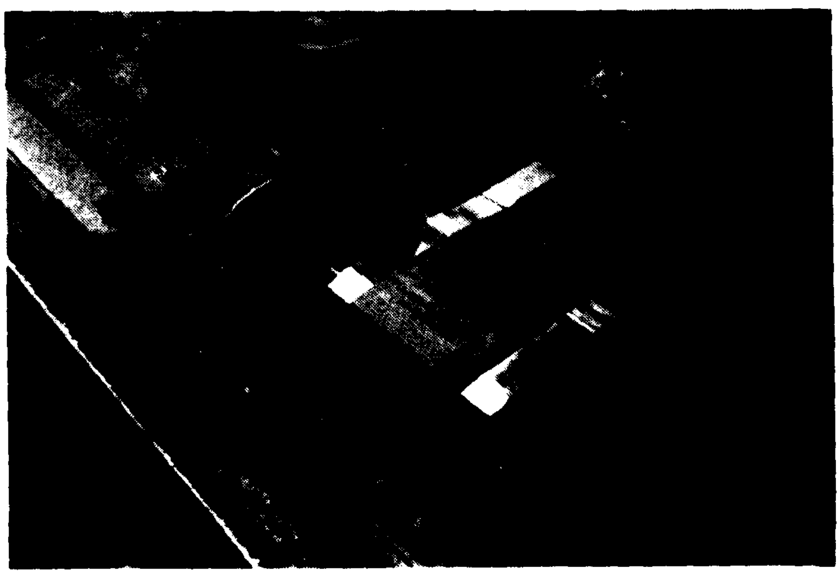


Figure 4-40. Machining Phenolic Tip Block.

Aluminum honeycomb was machined in the HOBE as shown in Figure 4-41. It was then expanded, cut in half to yield the right and left blade cores and prepared for bonding by vapor degreasing.

Figure 4-41. Machining Honeycomb Before Expansion (HOBE).

The stainless steel abrasion strips and bushings were purchased parts. The strips were sulfuric acid etched for bonding while the bushings were solvent cleaned and primed.

4.3.3 Blade Assembly and Cure

All details were prefitted into the assembly prior to bonding. Figure 4-42 shows the layup sequence and components for the blade. The upper and lower mold inserts with details assembled for the final bond cycle are shown in Figures 4-43 and 4-44.

Narmco 1113 epoxy supported film adhesive was used between skins, strap and skins, and skins and honeycomb. Unsupported film was used between all other glass and metal surfaces including strips, doublers, root, and tip blocks.

Figures 4-45 and 4-46 show the final loading operation after the insert has been closed on the assembled details. A plastic sheet was used only on the first blade to catch any excess resin flow that might result in damage to the mold. No excess resin problems occurred.

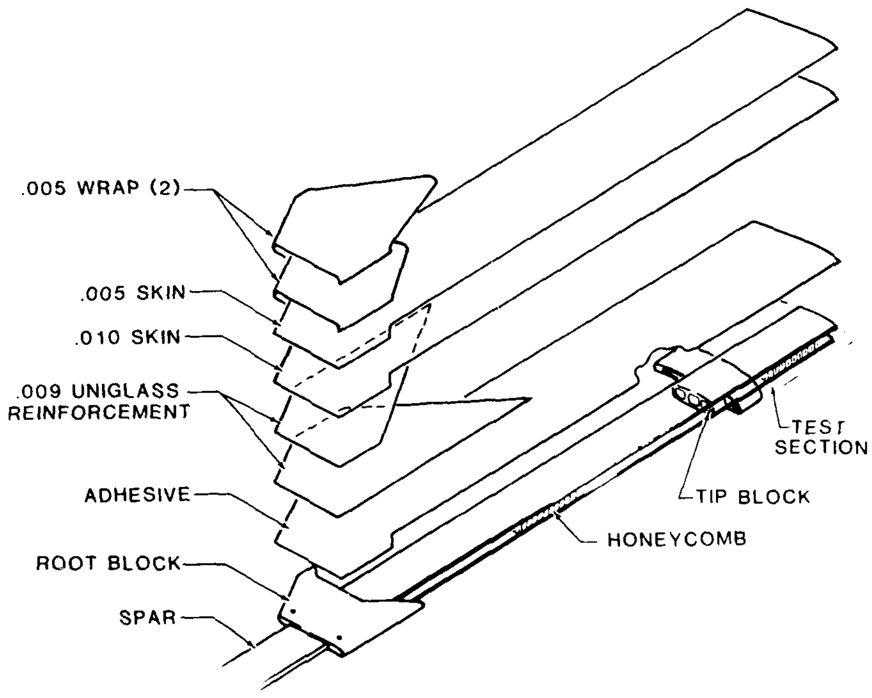


Figure 4-42. Layup Sequence for Upper Half of Blade - Lower Half Typical.

Figure 4-43. Details Assembled for the Final Bond Cycle.

Figure 4-44. Close-up of Assembly with Specific Details Itemized.

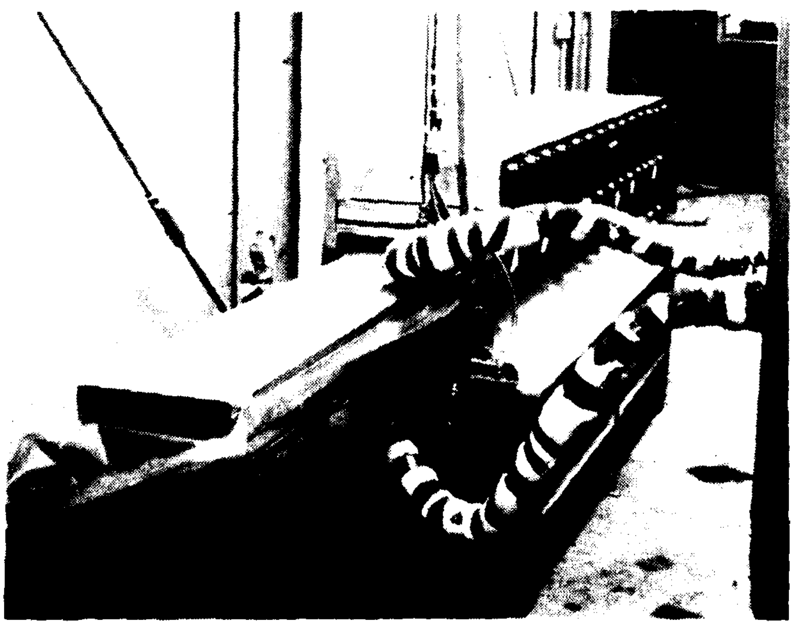


Figure 4-45. Loading Mold Insert.

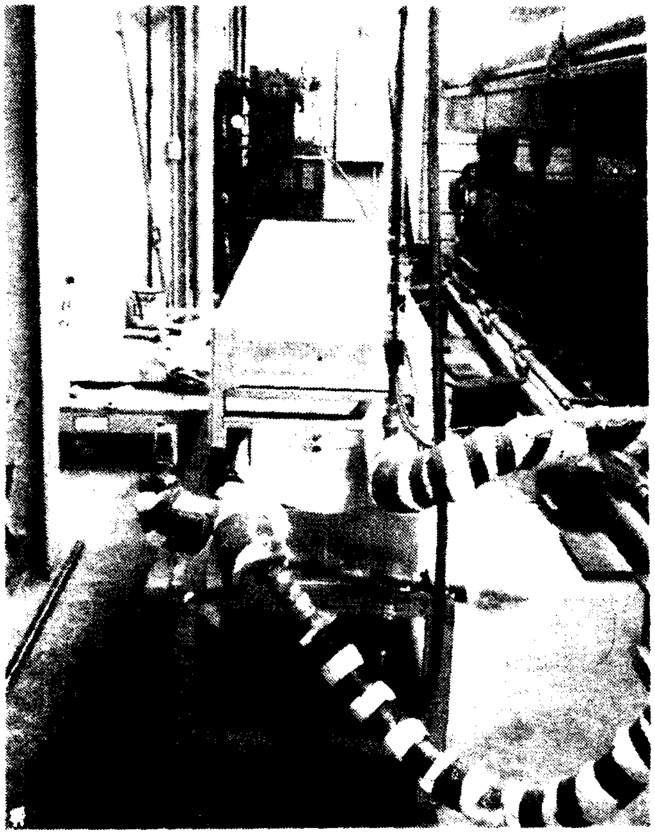


Figure 4-46. Mold Insert Loaded and Ready for Cure.

A typical temperature printout for the bearingless tail rotor bond cycle along with the placement of all themocouples is detailed in Figure 4-47. The insert thermocouples were placed in the bond line of the blade for optimum temperature monitoring and produced readings at 45-second intervals throughout the cycle. Fourteen minutes were required to bring the assembly into the cure range of 240°F to 280°F. The Narmco 1113 requires a cure of 60 minutes. A 16-minute cool down finished the cure for a total 90-minute cure cycle. The complete bond cycle is illustrated in Figure 4-48.

4.4 TASK IV - QUALIFICATION OF DEMONSTRATION BLADES

Under this task, the contract required that one demonstration blade be subjected to the same qualification tests as the research blade. These requirements were established in the approved test plan shown in Figure 4-49.

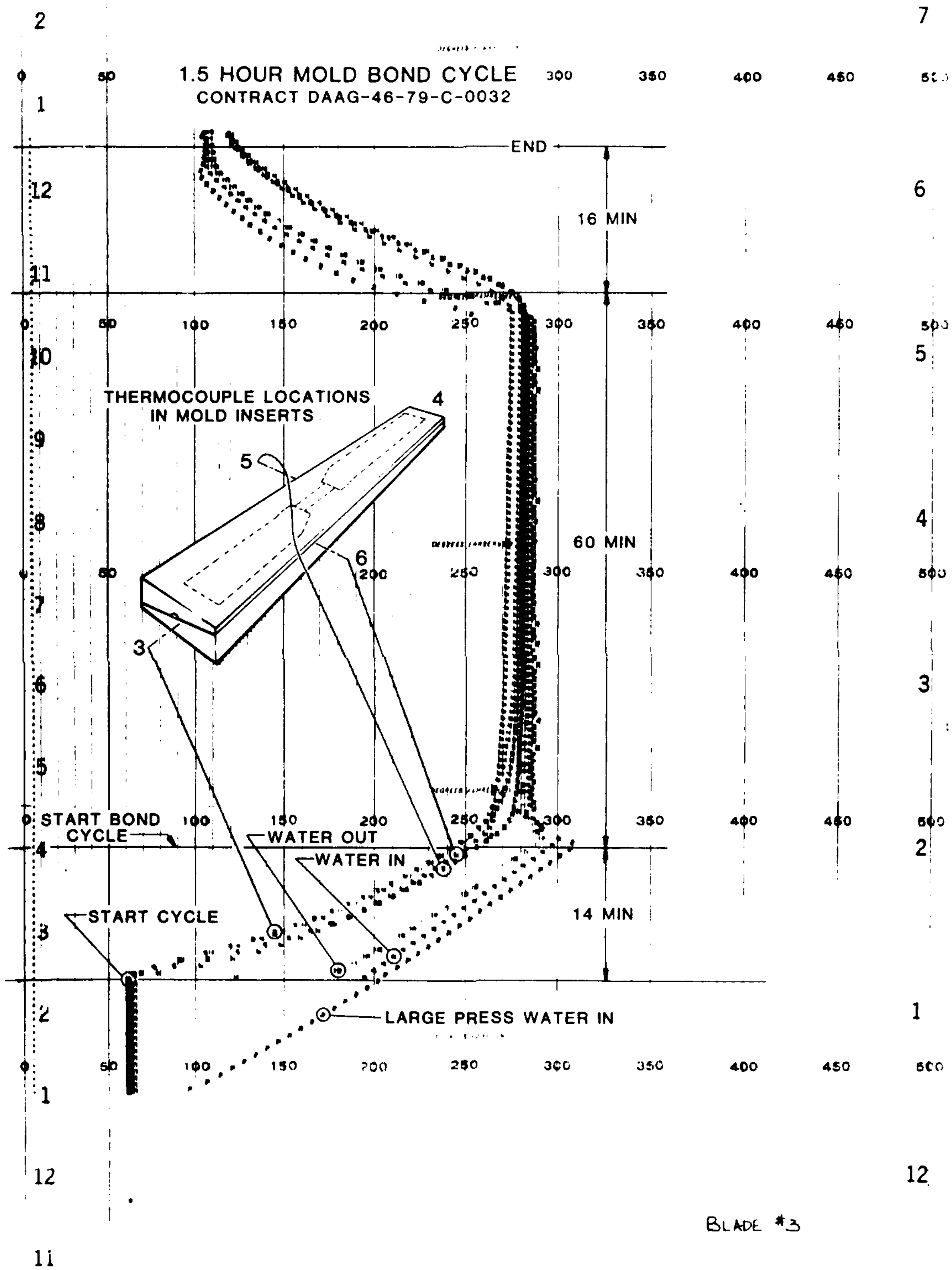


Figure 4-47. Temperature Printout for Bearingless Tail Rotor Bond Cycle.

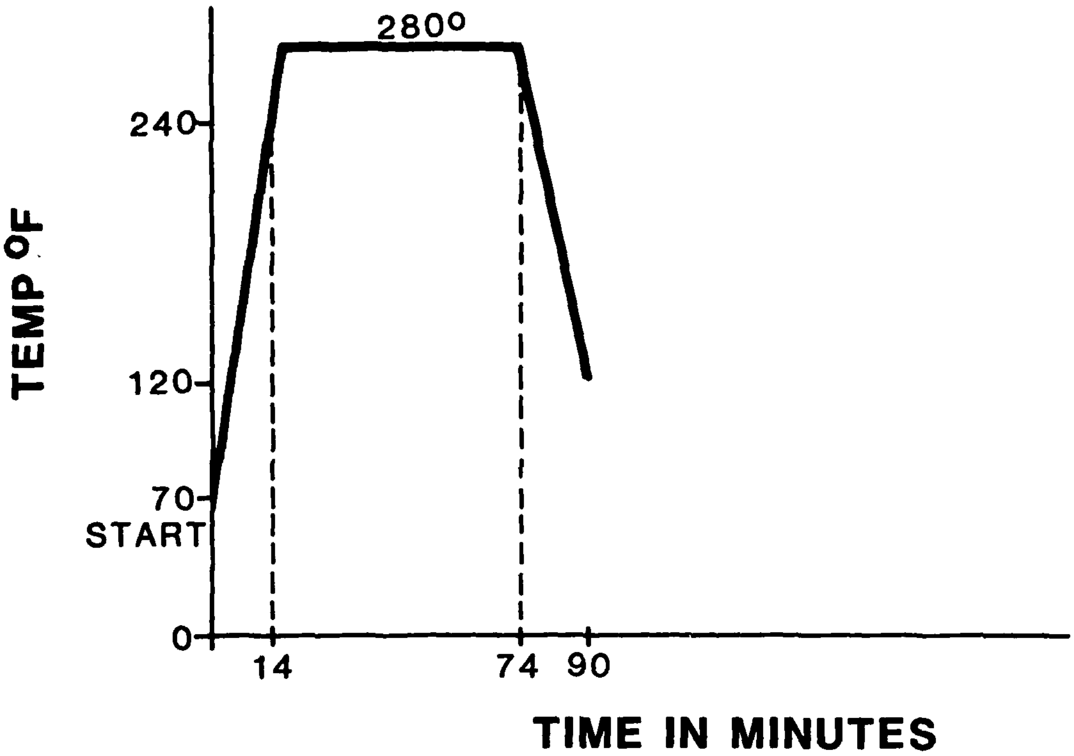
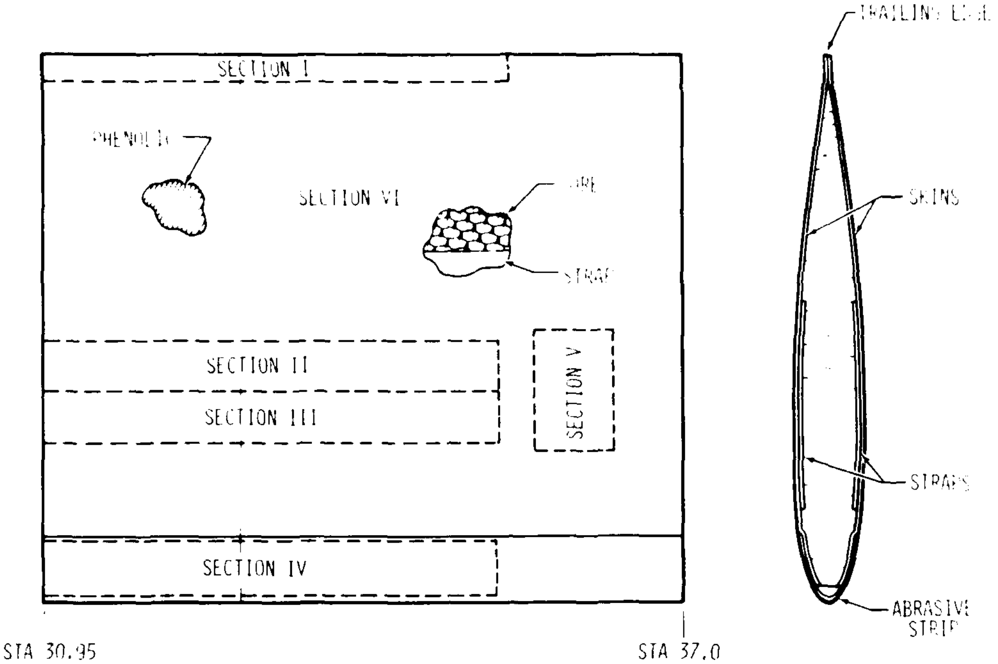


Figure 4-48. Complete Bond Cycle for Bearingless Tail Rotor.



LEGEND OF TESTS (599-318-103 TAIL ROTOR)

SECTION I - SHEAR TEST, UPPER TO LOWER SKIN, T.E. 2000 PSI BOND FAILURE OR 1600 PSI GLASS FAILURE.

SECTION II - SHEAR TEST, STRAP TO TIP BLOCK, TOP AND BOTTOM. 1100 PSI MINIMUM.

SECTION III - SHEAR TEST - SKIN TO STRAP, TOP AND BOTTOM. 2500 PSI BOND FAILURE OR 1600 PSI GLASS FAILURE.

SECTION IV - SHEAR TEST - ABRASIVE STRIP TO SKIN, TOP AND BOTTOM. 2500 PSI BOND FAILURE OR 1600 PSI GLASS FAILURE.

SECTION V - RESIN CONTENT - STRAPS, TOP AND BOTTOM. RESIN CONTENT (CURED) SHALL BE 26 TO 31 PER CENT.

SECTION VI - BOND LINE QUALITATIVE EVALUATION, REMAINDER OF TIP SAMPLE. THERE SHALL BE NO VOIDS OR DELAMINATIONS.

NON-DESTRUCTIVE TESTS WILL CONSIST OF VISUAL INSPECTION, TAPPING AND ULTRASONIC/RADIOGRAPHIC TECHNIQUES AS NECESSARY.

Figure 4-49. Test Plan - Outboard Tip Sample.

4.4.1 Destructive Tests

The blade portion of each rotor was fabricated 6 inches longer than required to provide excess for destructive testing. The tip block and spar strap extended into this area with additional honeycomb core added outboard of the block. In this way, all major elements of the blade were represented for testing purposes. Figure 4-50 shows both ends of the trimmed off sections before cutting into test specimens.

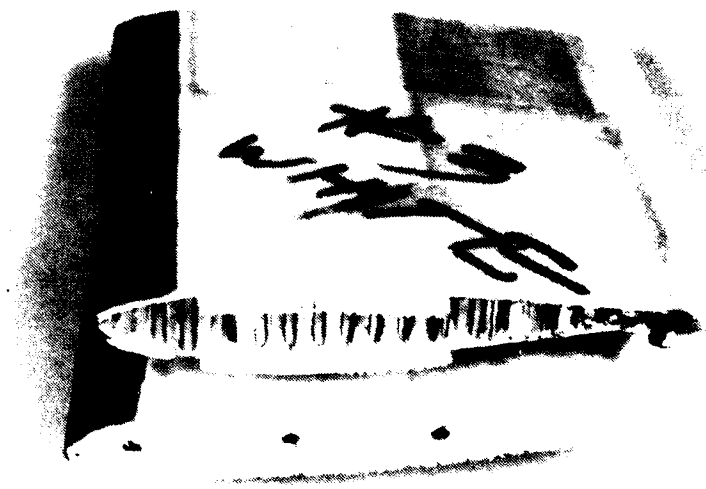


Figure 4-50. Blade Tip Test Sections.

Figure 4-51 is a typical laboratory report recording results for tests performed on that particular blade. A summary of destructive tests for all of the demonstration blades is shown in Table 4-4. Lab test reports are included in Appendix D.

The results from all tests were as anticipated except for a trailing edge glass failure and a bottom abrasion strip bond, both on blade No. 2. Although the trailing edge values were low, it was demonstrated that the bond line produced in the mold was adequate to force a failure in the skin laminate which was a precured detail. It was concluded that low values for the abrasion strip bond test resulted from over heating of the steel during preparation of the specimen.

Bell Helicopter TEXTRON

POST OFFICE BOX 482 • FORT WORTH, TEXAS 76101

Material Type: N1113 Adhesive
Batch
Roll
Primer
Batch

599-318-103

LABORATORY REPORT
ADHESIVES AND PLASTICS

REPORT: DT80-34A
DATE: 3-7-80
PREPARED BY: J. Peckham
TESTED BY: J. Peckham
APPROVED: ICG

Copies to:

TITLE: Destructive Test
TYPE TEST
REF. N. B. PAGE

Bonding Condition
Time
Temp. °F
psi
Material
Preparation
Date

Average
High
Low

Blade No. 1A - white

IDENTIFICATION	LENGTH	WIDTH	AREA	LOAD	BONDLINE THICKNESS	TYPE FAILURE	STRENGTH (PSI) (PLI)	REMARKS
I	.263	.268	.070	240		Adhes.	3426	
II Top	.270	.497	.134	170		Block	1268	
II Bot	.289	.502	.145	200		Block	1379	
III Top	.247	.483	.119	300		Glass	2521	
III Bot	.251	.493	.123	280		Glass	2276	
IV Top	.249	.463	.115	400		Glass	3478	
IV Bot	.229	.435	.099	400		Glass	4040	
V Top	--	--	--	--		--	24.62 percent	
V Bot	--	--	--	--		--	25.00 percent	
VI	ACCEPTABLE							

Figure 4-51. Destructive Test Laboratory Report.

Table 4-4. Destructive Test Summary.

Bearingless Tail Rotor Blade

Contract No. DAAG46-79-C-0032

Test Section	Note: Blades are identified red end and white end		Required Values*		Blade #1A Red	Blade #1A White	Blade #2 Red	Blade #2 White	Blade #3 Red	Blade #3 White
I	Shear Test	(Trailing Edge)	2000 PSI A/C or 1600 PSI G		2586C	3428A	1428G	1470G	3076G	2933G
II	Shear Test	(Strap to Tip Block)	1100 PSI Min.	Upr Lwr	1764A 1911B	1268B 1379B	1716B 1538B	1438B 1690B	1666B 1746B	1450B 1605B
III	Shear Test	(Skin to Strap)	2500 PSI A/C or 1600 PSI G	Upr Lwr	1946G 2000G	2521G 2276G	2678G 2313G	1769G 1832G	1780G 2255G	2519G 1946G
IV	Shear Test	(Abrasion Strip to Skin)	2500 PSI A/C or 1600 PSI G	Upr Lwr	1800G 2264G	3478G 4040G	2564G 1747A	3125G 842A	3966G 4054C	3174G 2400G
V	Resin Content	(Straps)	26 to 31%	Upr Lwr	28% 26%	25% 25%	27% 26%	26% 27%	27% 24%	23% 19%
VI	Bond Line Evaluation	(Qualitative)			Acceptable		Acceptable		Acceptable	

*Alpha Designations for Type of Failure: A - Adhesive B - Block; C - Cohesive G - Glass

When specimens yielded shear values below minimum requirements, additional specimens from the same section were prepared and tested. Difficulties were encountered in preparing lap shear specimens due to the thin skin laminate. In some instances cuts too shallow or past the bond interface resulted in interlaminar shear rather than lap shear. Figure 4-52 illustrates fabrication of the lap shear specimens.

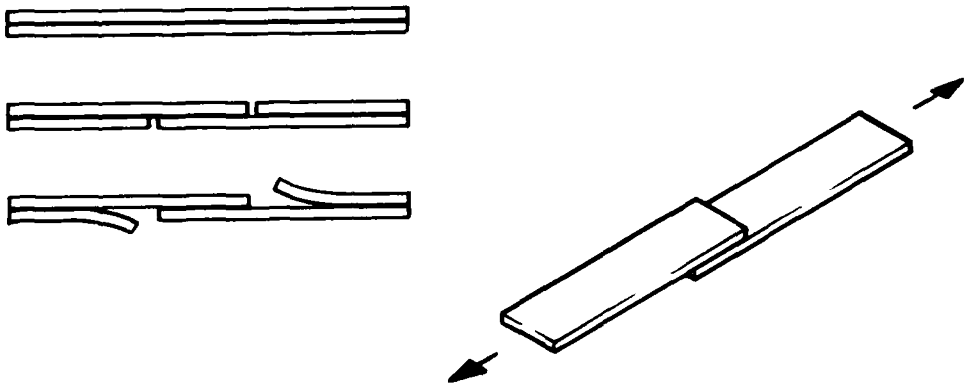


Figure 4-52. Preparation of Lap Shear Specimens.

All lap shear tests were conducted on the Speedy Tester (Figure 4-53) located in the BHT Methods and Materials Laboratory. All destructively tested specimens (Figure 4-54 typical) were retained for future examination and reference.

4.4.2 Nondestructive Tests

The demonstration blades were nondestructively evaluated by the BHT Quality Assurance Department. The blades were examined visually, tested for voids by tapping hammer method, and x-rayed for detail fit and location. Figure 4-55 shows both the root end and tip. The dark stripe represents the stainless steel leading edge. Tracer fibers in the fiberglass spar can be seen running the span. No defects of consequence to the program were revealed.

The three demonstration blades along with a research bearingless tail rotor are displayed in Figure 4-56. One demonstration blade was painted and included as one of the two required for delivery to the Army. Figure 4-57 shows both of these blades boxed for shipment.

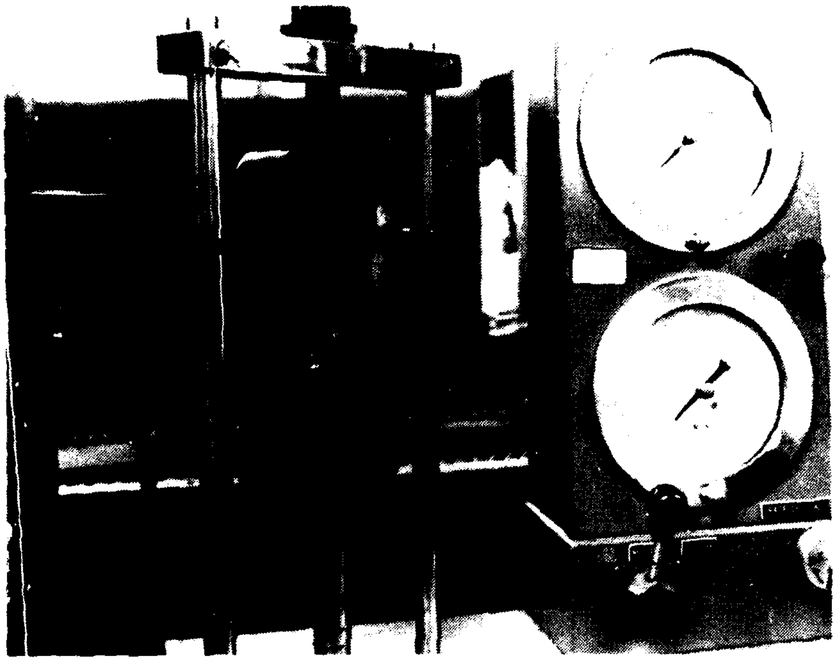


Figure 4-53. Lap Shear Tests.

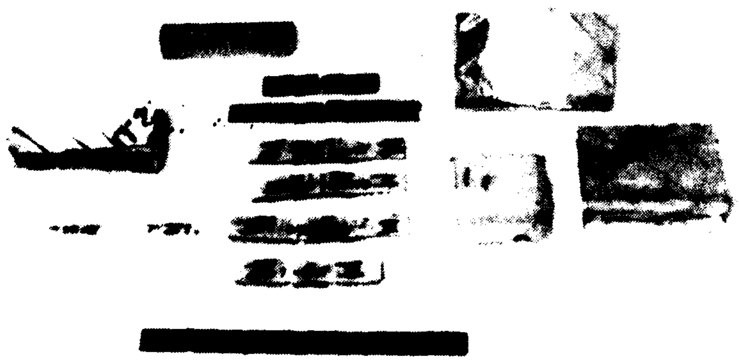


Figure 4-54. Destructive Test Specimens.

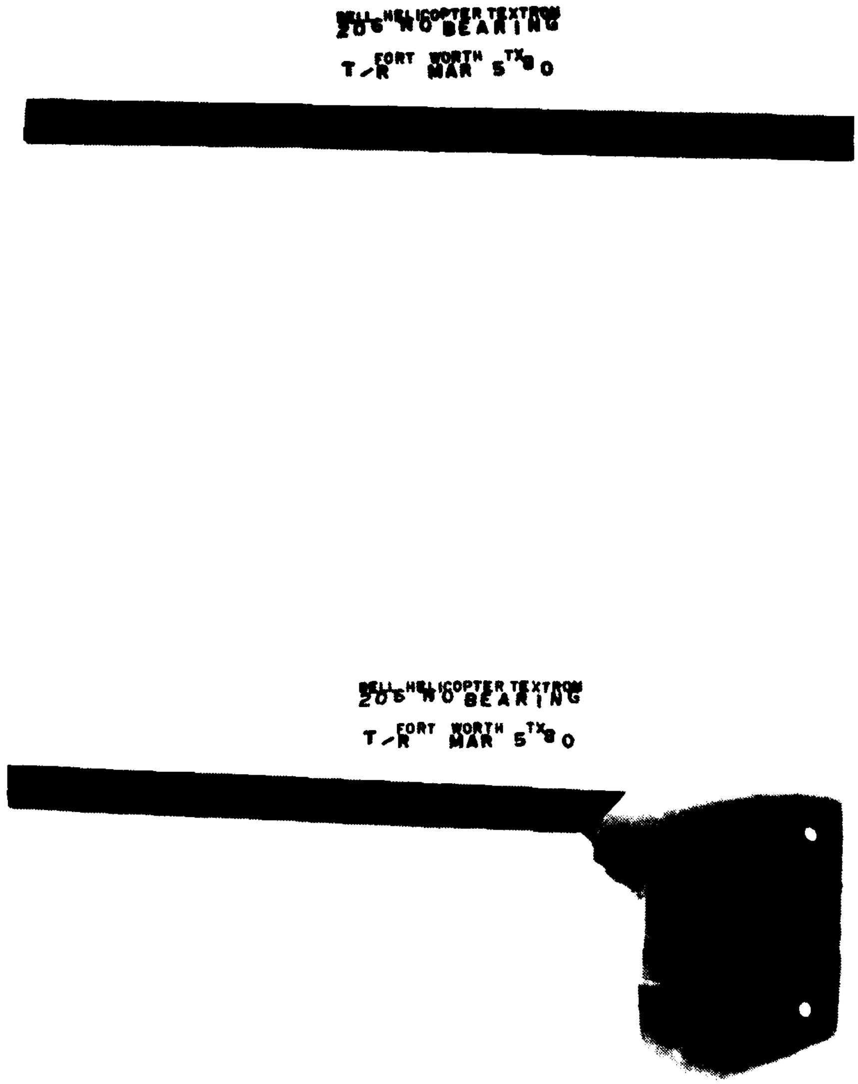


Figure 4-55. X-rays of Blade Showing Location of Details.

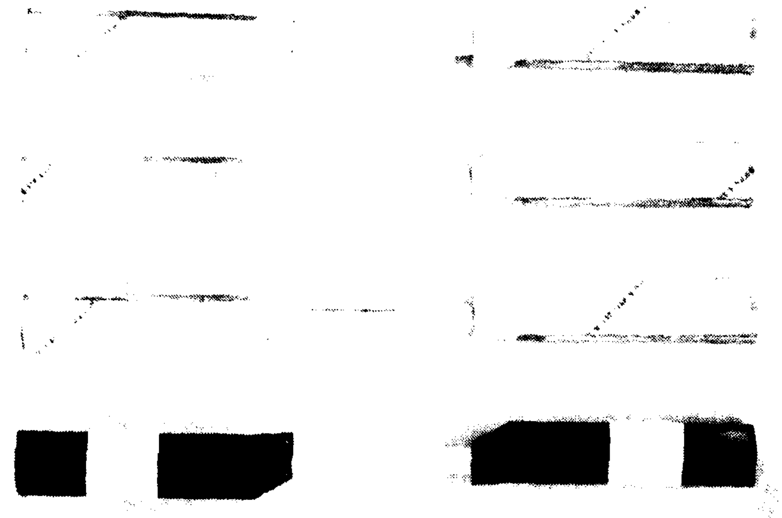


Figure 4-56. Three Finished Demonstration Blades with Research Blade.

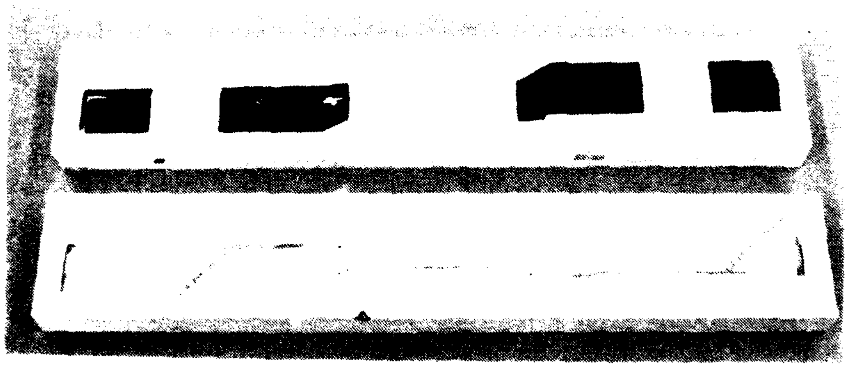


Figure 4-57. Two Bearingless Tail Rotor Blades Boxed for Shipment.

4.5 TASK V - COST ANALYSIS

A cost analysis was conducted to establish the economic benefit of the system. The analysis encompassed tooling, manufacturing labor, materials and energy.

Studies were conducted to determine the cost of producing quantities up to 1000 blades using the MM&T mold. Additionally, comparisons were made between the research and demonstration programs and the MM&T mold versus autoclave curing.

Since the thrust of the program was the development of a low cost, energy efficient mold system, optimization of the manufacturing approach was secondary. The primary purpose for the cost analysis was to generate comparative data to substantiate the performance of the mold.

4.5.1 Tooling

Actual tooling costs were analyzed for the research and MM&T demonstration programs and estimated for production.

The research blades were fabricated using a half-span mold and a spar strap mold. The tooling package for this blade was vendor fabricated for BHT at a cost of $5,200 in 1977.

Fabrication cost of the integrally heated mold was $4,149 for raw material and 1,026 man-hours in design and manufacture. A breakdown of the raw materials is listed in Table 4-5 with a comparison of both blade programs in Table 4-6.

Table 4-5. Tooling Raw Material Costs for MM&T Blade Mold

• HARDWARE		$2,632.51
STEEL	FLATS, ANGLE, TUBING, ROUNDS, BAR	
ALUMINUM	SHEETS, ANGLE, BILLET	
PIPE	TEES, NIPPLES, ELBOWS, REDUCERS, CAPS, BUSHINGS, UNION, SLEEVES, FLARE NUT	
MISCELLANEOUS	SCREWS, NUTS, WASHERS, CAP SCREWS	
VALVE	BALL	
• HOSES	FLEX	240.60
• INSTRUMENTATION	THERMOCOUPLES, FLOWMETER, GAUGE	401.39
• INSULATION BOARD		194.50
• PANELCOILS		680.00
		$4,194.00

Table 4-6. Program Cost Comparison

	MM&T PROGRAM	VS	RESEARCH PROGRAM
• TOOLING			
DESIGN	242 MH		$5,200 FOR HALF SPAN
FAB	784 MH		
RAW MATERIAL	$4,149		
• BLADE MATERIAL	$ 327/BLADE		$327/BLADE
• BLADES PRODUCED	4		3
• LABOR (BLADES)	775 MH		440 MH

In a production situation, the integrally heated mold is estimated to have a capacity of five blades per two-shift day. Five sets of autoclave tools would be required to produce an equivalent quantity of blades. As noted in Table 4-6, the fabrication cost of an integrally heated mold was 784 man-hours and $4,149. In comparison, an autoclave tool is estimated to cost 300 man-hours and $750 in tooling materials. Table 4-7 compares the tooling cost for producing five blades per day by mold and by autoclave.

Table 4-7. Comparison of Capacity Cost

	Quantity of Tools Required	Tooling Man-Hours	Tooling Material
MM&T Mold	1	784	$4149
Autoclave Tools	5	1500	$3750

Based on a $50 per hour labor rate, tooling costs for five blades per day capability would be $35,401 less for the mold than autoclave. The autoclave would also consume $15 of perishable bagging material per blade.

4.5.2 Labor

Labor cost analysis took into account the allocation of operations into direct and indirect labor categories. Table 4-8 lists these operations in their respective categories. For the sake of simplicity, hour totals used in this presentation include all vendor work converted from dollars to man-hours.

Table 4-8. Labor Operations.

INDIRECT LABOR	DIRECT LABOR
• LOAD AND UNLOAD OVEN	• GATHER MATERIALS
• BAG FOR AUTOCLAVE	• CUT TEMPLATES
• AUTOCLAVE CURE	• LAYUP GLASS
• DEBAG	• MACHINE HONEYCOMB CORE AND TIP BLOCKS
• WEIGH DETAILS	• CAST FORM ROOT BLOCKS ON SPAR
• CHEMICAL TREAT METAL DETAILS	• TRIM DETAILS
• WRAP, PACKAGE DETAILS	• STRETCH FORM ABRASION STRIP
• BOND ASSEMBLY	• PREPARE MOLDS
• FINISH	• PREFIT DETAILS
• DEGREASE	• APPLY ADHESIVE
• DEBURR	
• INSTALL BUSHINGS	
• PAINT	

The research program produced three blades at a labor cost of 440 hours. It should be noted that these hours were extracted from the history of a program that had as its primary purpose, the development and flight test of a bearingless tail rotor. The low labor content recorded for the research blades is attributed to the fact that judicious tracking of associated blade fabrication hours was not a program requirement as was the case for the MM&T demonstration blades.

Four prototype demonstration blades were fabricated at a cost of 775 man-hours as shown in Table 4-6. The first blade was used for tool tryout and was destructively tested. Actual man-hours were recorded to assist in projecting production costs. The first blade consumed 271 man-hours and the last, 131 man-hours showing a learning curve of about 75 percent.

The manufacture of 1, 10, 100 and 1000 blades in the MM&T mold was projected using an 85 percent learning curve, to accommodate production methods and tooling (Figure 4-58). The plot shows the first production blade would take 114 man-hours and blade number 1000 would require 23 man-hours. This shows the economies of scale in operator proficiency and the additional tools to provide precut kits and separate skin assemblies.

Autoclave curing from the standpoint of the learning curve would add three man-hours to the whole curve making it 117 man-hours at blade number one and 26 man-hours at 1000 blades. The difference is attributed to bagging, debagging, and other autoclave related labor requirements.

Cocuring the skins during assembly bonding would eliminate the processing associated with precuring. The resulting labor savings would be 29 hours at blade number 1 and 4 hours at blade 1000 (Figure 4-59).

4.5.3 Energy

In Section 4.2.4, it was pointed out that the calculated energy requirements for the panel coil system was far lower than that for the other systems. When the blades were cured as described in 4.3.3, it was found that the system performance surpassed expectations. Measured units of temperature, water volume and time revealed energy consumption of 19.71 kwh for a complete cure cycle rather than 23.62 kwh as originally calculated. Figure 4-60 shows the actual calculations and Figure 4-61 is a final energy comparison of all of the candidate systems.

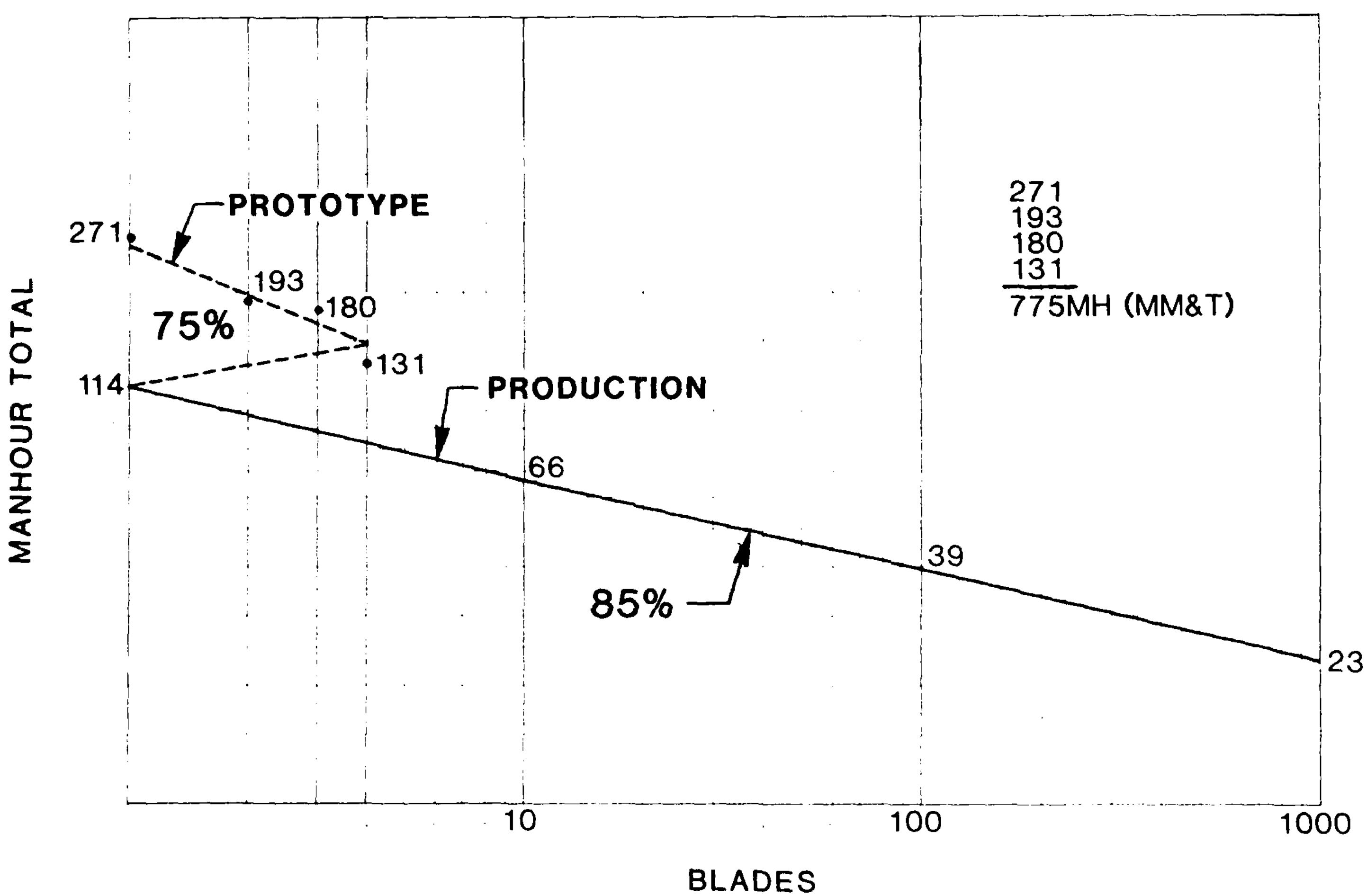


Figure 4-58. Prototype and Production Man-hour Projections for Blades Produced with MM&T Mold.

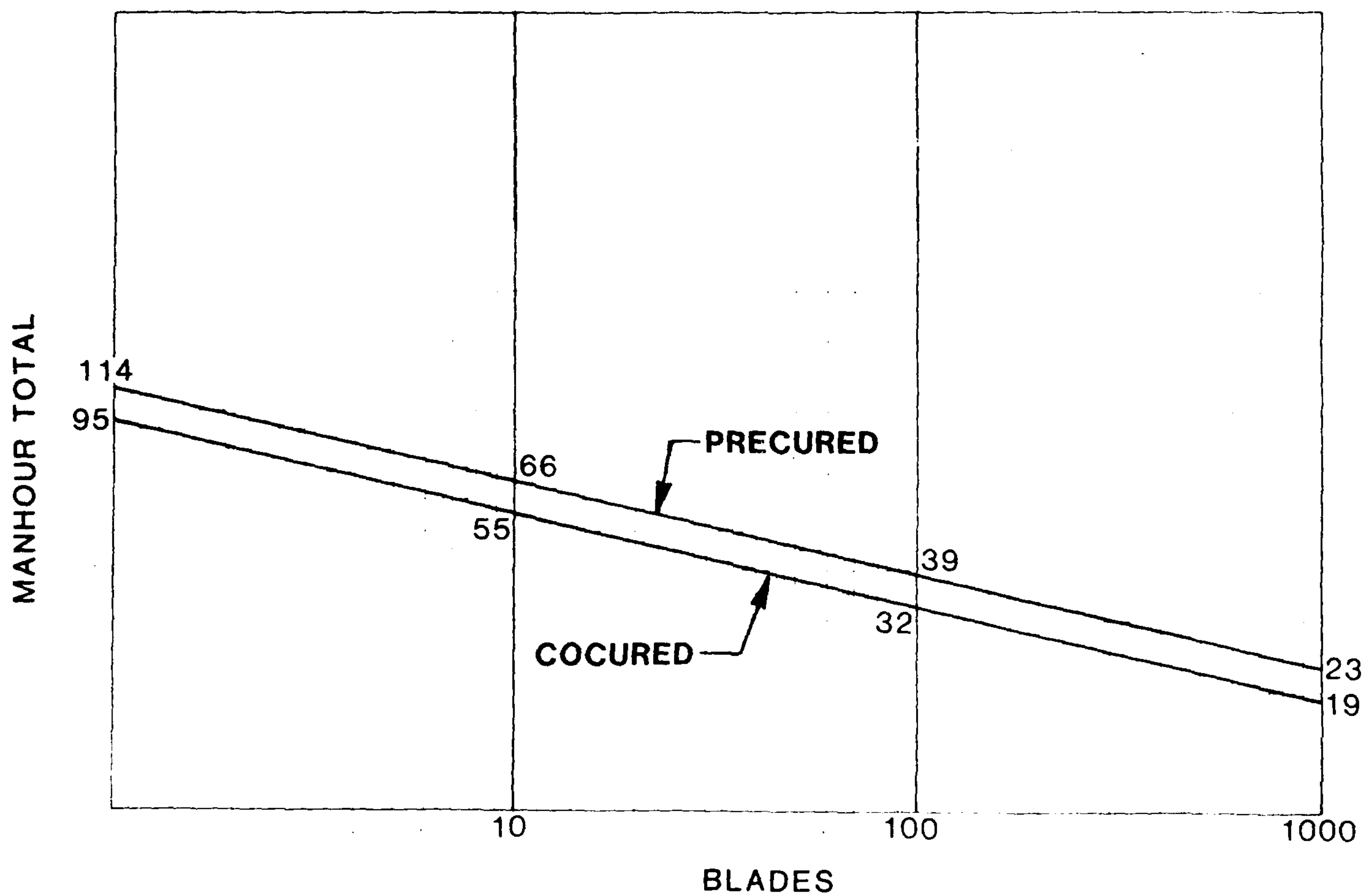


Figure 4-59. Precured Detail Assembly Versus Cocured Assembly.

A. POWER REQUIREMENT FOR INITIAL HEAT-UP — ACTUAL

1. Heat absorbed by: COMPLETE CURE CYCLE (PANEL COIL - AL INSERT)

$$\frac{\text{Weight of Material (Lb)} \times \text{Specific Heat (BTU/Lb-F)} \times \text{Temp. Dif. (Final-Initial) (F)}}{3412 \text{(BTU/KWH)} \times \text{(Time in Hours)}}$$ ______ KWH

2. Heat absorbed by: WATER

$$\frac{10.2 \text{ GAL. } 85.068 \text{ LB.} \times 1.0 \times 200°F \times 30 \text{ MIN.}}{3412 \times .5}$$ 9.98 KWH

3. Heat absorbed by: WATER TO RAISE PARTS TO TEMP.

$$\frac{85.068 \text{ LB/MIN.} \times 1.0 \times 10°F \times 30 \text{ MIN.}}{3412 \times .5}$$ 7.48 KWH

4. Heat absorbed by: WATER TO MAINTAIN OPERATING TEMP (CURE)

$$\frac{85.068 \text{ LB/MIN.} \times 1.0 \times 1°F \quad 60 \text{ MIN.}}{3412 \times .5}$$ 1.5 KWH

5. Heat absorbed by: ______

$$\frac{\_\_\_ \times \_\_\_ \times \_\_\_}{3412}$$ ______ KWH

6. Heat absorbed by: ______

______ x ______ x ______ ______ KWH

Total Heat Requirement for Initial Heat-up: ______ ______ KWH

Total Power Requirement for Initial Heat-up: ______ 18.96 KWH

B. POWER REQUIREMENT FOR OPERATING HEAT

1. Heat Required to Replace Heat Losses: ______

$$\frac{\text{(Exposed Surf. Area) (sq. ft)} \times \text{(Heat Loss at Final Oper. Temp) (W/sq ft)} \times \text{(Cycle Time) Hrs)}}{1000 \text{ (W/KW)}}$$ ______ KWH

2. Heat Required to Replace Heat Losses: ______

$$\frac{\_\_\_}{1000}$$ ______ KWH

3. Heat Required to Replace Heat Losses: ______

$$\frac{\_\_\_}{1000}$$ ______ KWH

4. Heat Required to Replace Heat Losses: ______

$$\frac{\_\_\_}{1000}$$ ______ KWH

Circulation Pump: .75 KWH

Total Energy Use 19.71 KWH

Figure 4-60. Energy Consumption - Panel Coil Actual Cure Cycle Calculations.

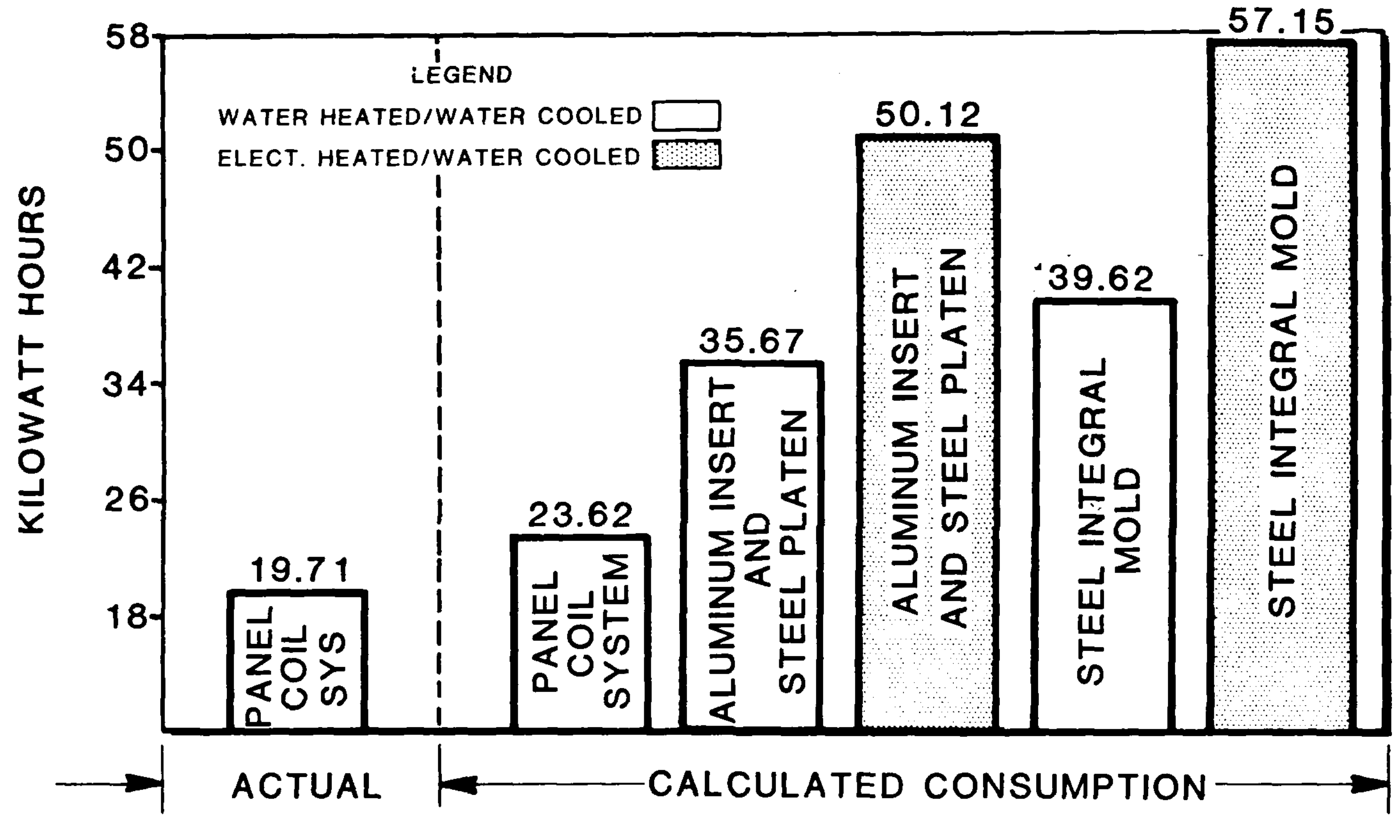


Figure 4-61. Final Energy Consumption Comparison for All Candidate Molds.

Additional energy savings could be realized by using stack molds as in Figure 4-62. Estimated savings are 25 percent in the second blade of a two-blade stack.

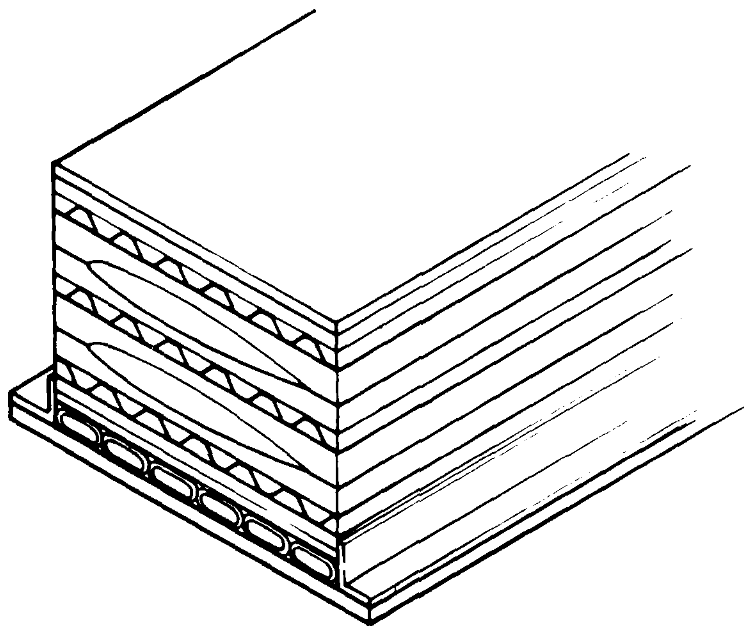


Figure 4-62. Two-blade Stack Mold.

Cure profiles were plotted for curing the bearingless tail rotor blade using the MM&T mold and two BHT production autoclaves, a 4' x 9', and a 5' x 18'. Figure 4-63 shows the large variation in cure cycles ranging from 90 minutes in the demonstration mold to 229 minutes in the large autoclave. The cure profiles show the MM&T mold can conserve large quantities of energy while providing excellent tool utilization.

Energy requirements of 114 kwh and 787 kwh respectively were calculated for a cure cycle in the 4' x 9' and 5' x 18' autoclaves (Figure 4-64). The requirements per blade for multi-blade bonding cycles are compared with the MM&T mold in Table 4-9. The values are displayed graphically in Figure 4-65.

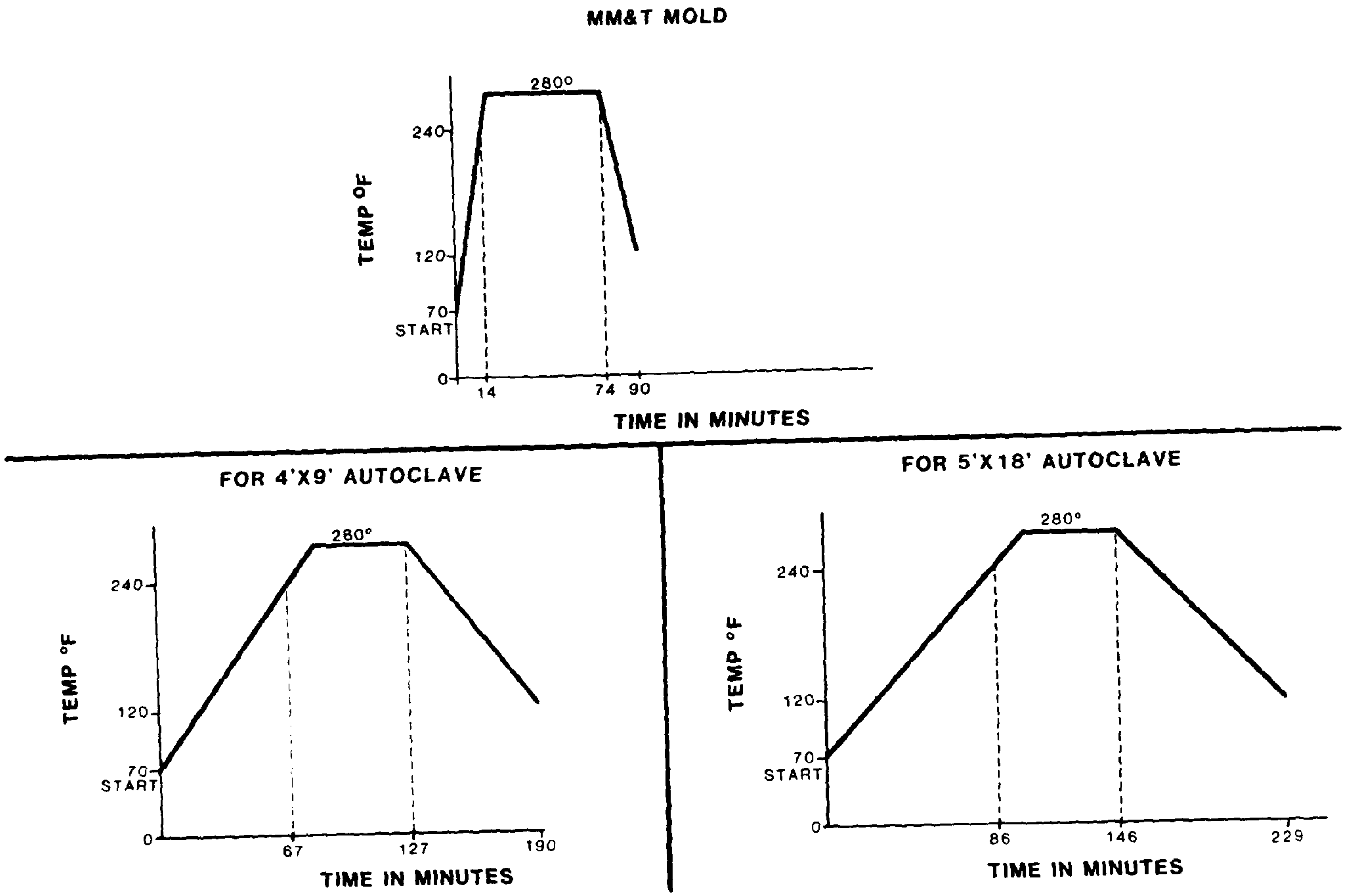


Figure 4-63. Cure Cycle Profile Comparisons.

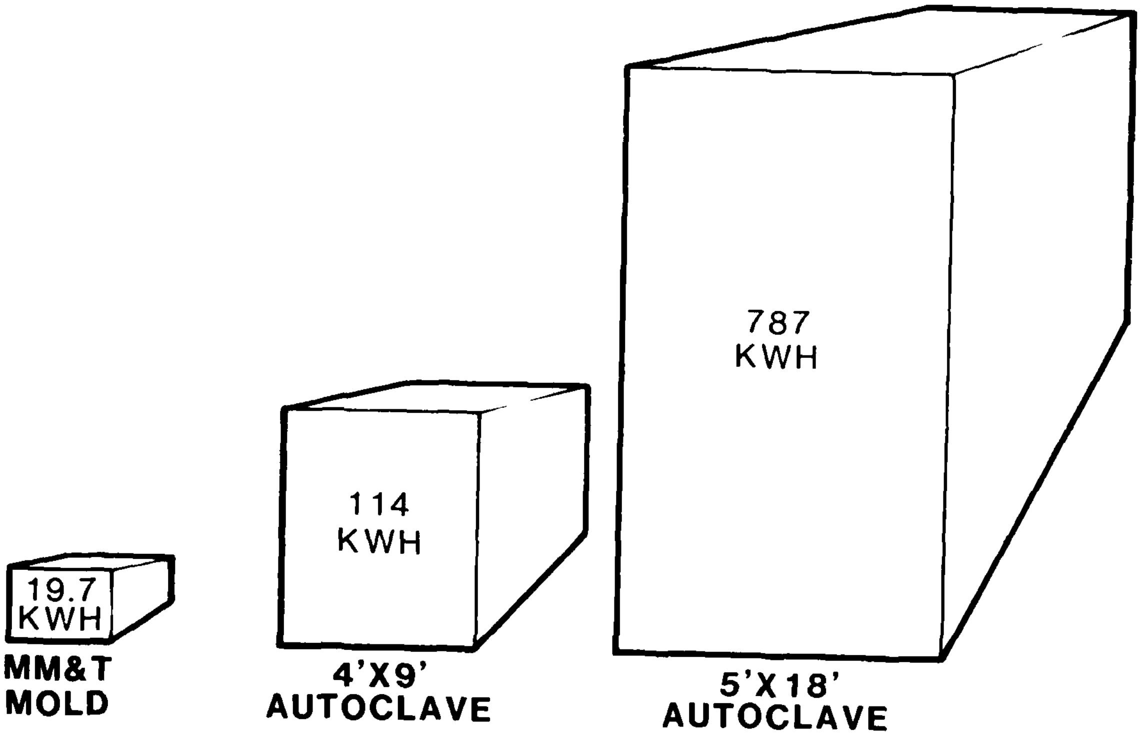


Figure 4-64. Energy Requirements for One Cure Cycle.

Table 4-9. Energy Required for Bonding Tail Rotor Blades

MM&T	Number of Tools	Small Autoclave	Large Autoclave
19.7 kwh	1	114.0 kwh	787.0 kwh
	2	57.0	393.5
	3	38.0	262.3
	4	28.5	196.8
	5	22.8	157.4
	6	19.0	131.2
	7		112.4
	8		98.4
	9		87.4
	10		78.7
	11		71.5
	12		65.6
	13		60.5
	14		56.2
	15		52.5
	16		49.2
		Capacity (6)	Capacity (16)

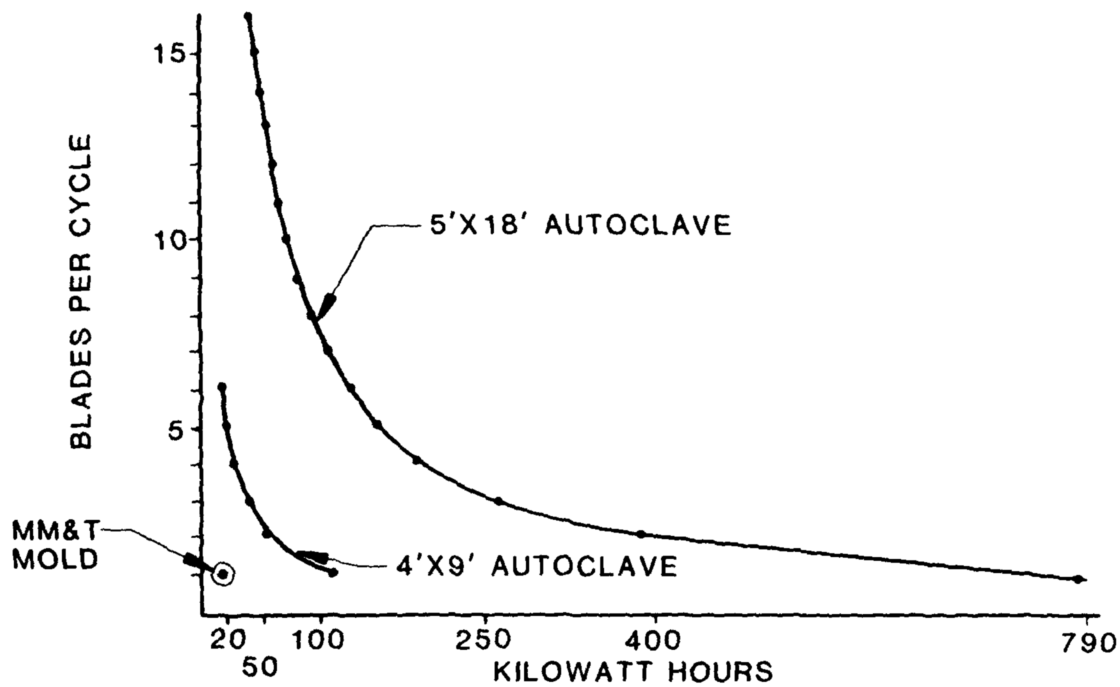


Figure 4-65. Energy Requirements Comparison - MM&T Mold Versus Autoclave.

At production rates of less than twenty blades per month, the MM&T mold conserves up to 83 percent of the energy consumed by the smaller autoclave if a single tool is utilized. When production rates in excess of one hundred blades per month are achieved, five autoclave tools would be used versus one mold. At that point, the energy costs are approximately equal, but the use of the mold provides a 45 percent reduction in tooling costs.

5. CONCLUSIONS

The program objective to fabricate and demonstrate a low cost, energy efficient mold system was met.

- Low Cost Mold - The MM&T system can be fabricated at a lower cost than an autoclave and supporting production tools. The mold insert concept developed during this program introduced an element of versatility not possible with conventional integral molds.

- 52 Percent Reduction in Cure Cycle - The MM&T mold is more compact and thermally efficient than an autoclave; Consequently, the cure cycle is faster and allows better tool utilization.

- 83 Percent Reduction in Energy - Substantially less energy is consumed during operation of the MM&T mold as compared to an autoclave. Savings of this type will become even more significant as the cost of energy continues to increase.

- Other cost savings are realized by eliminating the need for autoclave bagging and sealing. Also, fewer tools are required to meet production rates.

6. RECOMMENDATIONS

The mold developed for this MM&T program was demonstrated to be efficient in the production of composite tail rotor blades. The principles established are applicable to a variety of bonding and curing operations.

- Expand Technology to Laminated Structures - Additional development is recommended to apply the principles established to the curing and bonding of large multi-layer, laminated structures.

- Apply Technology to Curved Components - The system has applicability to the curing of contoured panels. This would involve manufacturing methods for contoured panel coils.

- Develop Mobile System - A transportable system based on these principles should be developed. The need exists for mobile units capable of supporting work cell manufacturing concepts and related technology such as that emerging from the ICAM program.

Appendix A

A. POWER REQUIREMENT FOR INITIAL HEAT-UP ESTIMATED

1. Heat absorbed by: INTEGRAL STEEL MOLD-ELECT. HT./WATER COOLED

$$\frac{\text{Weight of Material (Lb)} \times \text{Specific Heat (BTU/Lb-F)} \times \text{Temp. Dif. (Final-Initial) (F)}}{3412\text{(BTU/KWH)} \times \text{(Time in Hours)}} = \underline{\qquad}\ \text{KWH}$$

2. Heat absorbed by: STEEL MOLD

$$\frac{2892\ \text{LBS.} \times .12 \times 200°\text{F} \times 30\ \text{MIN.}}{3412 \times .5} = 40.68\ \text{KWH}$$

3. Heat absorbed by: TAIL ROTOR BLADE

$$\frac{3.4\ \text{LBS.} \times .197 \times 200°\text{F} \times 30\ \text{MIN.}}{3412 \times .5} = .08\ \text{KWH}$$

4. Heat absorbed by: WATER

$$\frac{85.068\ \text{LBS.} \times 1.0 \times 200°\text{F} \times 20\ \text{MIN.}}{3412 \times .5} = 9.97\ \text{KWH}$$

5. Heat absorbed by: ______

$$\frac{\underline{\qquad} \times \underline{\qquad} \times \underline{\qquad}}{3412} = \underline{\qquad}\ \text{KWH}$$

6. Heat absorbed by: ______

$$\underline{\qquad} \times \underline{\qquad} \times \underline{\qquad} = \underline{\qquad}\ \text{KWH}$$

Total Heat Requirement for Initial Heat-up: ______ ______ KWH

Total Power Requirement for Initial Heat-up: ______ 50.73 KWH

B. POWER REQUIREMENT FOR OPERATING HEAT

1. Heat Required to Replace Heat Losses: ______

$$\frac{\text{(Exposed Surf. Area) (sq. ft)} \times \text{(Heat Loss at Final Oper. Temp) (W/sq ft)} \times \text{(Cycle Time) Hrs)}}{1000\ \text{(W/KW)}} = \underline{\qquad}\ \text{KWH}$$

2. Heat Required to Replace Heat Losses: STEEL MOLD

$$\frac{19.01\ \text{SQ. FT.} \times 180\ \text{WATTS SQ. FT.} \times 1\ \text{HR.}}{1000} = 3.42\ \text{KWH}$$

3. Heat Required to Replace Heat Losses: ______

$$\frac{\underline{\qquad}}{1000} = \underline{\qquad}\ \text{KWH}$$

4. Heat Required to Replace Heat Losses: ______

$$\frac{\underline{\qquad}}{1000} = \underline{\qquad}\ \text{KWH}$$

Circulation Pump: 3.0 KWH

Total Energy Use 57.15 KWH

A. POWER REQUIREMENT FOR INITIAL HEAT-UP ESTIMATED

1. Heat absorbed by: STEEL INTEGRAL MOLD - WATER HT./WATER COOLED

Weight of Material (Lb) x Specific Heat (BTU/Lb-F) x Temp. Dif. (Final-Initial) (F)
3412(BTU/KWH) x (Time in Hours) ______ KWH

2. Heat absorbed by: STEEL MOLD

1713 LBS. x .12 x 200°F x 30 MIN.
3412 x .5 24.1 KWH

3. Heat absorbed by: TAIL ROTOR BLADE

3.4 LBS. x .197 x 200°F x 30 MIN.
3412 x .5 .08 KWH

4. Heat absorbed by: WATER

85.068 LB. x 1.0 x 200°F x 30 MIN.
3412 x .5 9.97 KWH

5. Heat absorbed by:

x x
3412 ______ KWH

6. Heat absorbed by:

x x ______ KWH

Total Heat Requirement for Initial Heat-up: ______ KWH

Total Power Requirement for Initial Heat-up: 34.15 KWH

B. POWER REQUIREMENT FOR OPERATING HEAT

1. Heat Required to Replace Heat Losses:
(Exposed Surf. Area) (sq. ft) x (Heat Loss at Final Oper. Temp) (W/sq ft) x (Cycle Time) Hrs)
1000 (W/KW) ______ KWH

2. Heat Required to Replace Heat Losses: STEEL MOLD

13.73 SQ. FT. SUR. x 180 WATTS x 1 HR.
1000 2.47 KWH

3. Heat Required to Replace Heat Losses:

1000 ______ KWH

4. Heat Required to Replace Heat Losses:

1000 ______ KWH

Circulation Pump: 3.0 KWH

Total Energy Use 39.62 KWH

A. POWER REQUIREMENT FOR INITIAL HEAT-UP ESTIMATED

1. **Heat absorbed by:** STEEL PLATTENS, AL INSERTS - ELECT. HT./WATER COOLED

$$\frac{\text{Weight of Material (Lb)} \times \text{Specific Heat (BTU/Lb-F)} \times \text{Temp. Dif. (Final-Initial) (F)}}{3412\text{(BTU/KWH)} \times \text{(Time in Hours)}} = \underline{\qquad} \text{ KWH}$$

2. **Heat absorbed by:** 2 PLATENS

$$\frac{2138 \text{ LBS.} \times .12 \times 200°\text{F} \times 30 \text{ MIN.}}{3412 \times .5} = 30.08 \text{ KWH}$$

3. **Heat absorbed by:** AL. INSERTS

$$\frac{178 \text{ LBS.} \times .23 \times 200°\text{F} \times 30 \text{ MIN.}}{3412 \times .5} = 4.8 \text{ KWH}$$

4. **Heat absorbed by:** TAIL ROTOR BLADE

$$\frac{3.4 \times .197 \times 200°\text{F} \times 30 \text{ MIN.}}{3412 \times .5} = .08 \text{ KWH}$$

5. **Heat absorbed by:** WATER

$$\frac{85.068 \text{ LB.} \times 1. \times 200°\text{F} \times 30 \text{ MIN.}}{3412} = 9.97 \text{ KWH}$$

6. **Heat absorbed by:** ______

______ x ______ x ______ ______ KWH

Total Heat Requirement for Initial Heat-up: ______ ______ KWH

Total Power Requirement for Initial Heat-up: ______ 44.93 KWH

B. POWER REQUIREMENT FOR OPERATING HEAT

1. **Heat Required to Replace Heat Losses:** ______

$$\frac{\text{(Exposed Surf. Area) (sq. ft)} \times \text{(Heat Loss at Final Oper. Temp) (W/sq ft)} \times \text{(Cycle Time Hrs)}}{1000 \text{ (W/KW)}} = \underline{\qquad} \text{ KWH}$$

2. **Heat Required to Replace Heat Losses:** (4 IN.) STEEL PLATENS

$$\frac{10.56 \text{ SQ. FT.} \times 180 \text{ WATTS SQ. FT.} \times 1 \text{ HR.}}{1000} = 1.9 \text{ KWH}$$

3. **Heat Required to Replace Heat Losses:** AL. MOLD INSERTS

$$\frac{3.17 \text{ SQ. FT.} \times 90 \text{ WATTS SQ. FT.} \times 1 \text{ HR.}}{1000} = .29 \text{ KWH}$$

4. **Heat Required to Replace Heat Losses:** ______

$$\frac{\qquad}{1000} = \underline{\qquad} \text{ KWH}$$

Circulation Pump: 3.0 KWH

Total Energy Use 50.12 KWH

A. POWER REQUIREMENT FOR INITIAL HEAT-UP ESTIMATED

1. **Heat absorbed by:** STEEL PLATEN, AL INSERT - WATER HT./WATER COOLED

$$\frac{\text{Weight of Material (Lb)} \times \text{Specific Heat (BTU/Lb-F)} \times \text{Temp. Dif. (Final-Initial) (F)}}{3412\,(\text{BTU/KWH}) \times (\text{Time in Hours})} = \_\_\_\_\ \text{KWH}$$

2. **Heat absorbed by:** STEEL PLATEN (2 IN. THICK)

$$\frac{1179\ \text{LBS.} \times .12 \times 200°F}{3412 \times .5} \times 30\ \text{MIN.} \qquad 16.58\ \text{KWH}$$

3. **Heat absorbed by:** AL. INSERTS

$$\frac{178\ \text{LBS.} \times .23 \times 200°F}{3412 \times .5} \times 30\ \text{MIN.} \qquad 4.8\ \text{KWH}$$

4. **Heat absorbed by:** TAIL ROTOR BLADE

$$\frac{3.4\ \text{LBS.} \times .197 \times 200°F}{3412 \times .5} \times 30\ \text{MIN.} \qquad .08\ \text{KWH}$$

5. **Heat absorbed by:** WATER

$$\frac{85.068\ \text{LBS.} \times 1.0 \times 200°F}{3412} \times 30\ \text{MIN.} \qquad 9.97\ \text{KWH}$$

6. **Heat absorbed by:** ____

____ x ____ x ____ ____ KWH

Total Heat Requirement for Initial Heat-up: ____ ____ KWH

Total Power Requirement for Initial Heat-up: ____ 31.43 KWH

B. POWER REQUIREMENT FOR OPERATING HEAT

1. Heat Required to Replace Heat Losses: ____

$$\frac{(\text{Exposed Surf. Area})\,(\text{sq. ft}) \times (\text{Heat Loss at Final Oper. Temp})\,(\text{W/sq ft}) \times (\text{Cycle Time})\,\text{Hrs}}{1000\ (\text{W/KW})} = \_\_\_\_\ \text{KWH}$$

2. Heat Required to Replace Heat Losses: STEEL PLATENS

$$\frac{5.28\ \text{SQ. FT.} \times 180\ \text{WATTS SQ. FT.} \times 1\ \text{HR.}}{1000} \qquad .95\ \text{KWH}$$

3. Heat Required to Replace Heat Losses: AL. MOLD INSERTS

$$\frac{3.17\ \text{SQ. FT.} \times 90\ \text{WATTS SQ. FT.} \times 1\ \text{HR.}}{1000} \qquad .29\ \text{KWH}$$

4. Heat Required to Replace Heat Losses: ____

$$\frac{\_\_\_\_}{1000} \qquad \_\_\_\_\ \text{KWH}$$

Circulation Pump: 3.0 KWH

Total Energy Use 35.67 KWH

A. POWER REQUIREMENT FOR INITIAL HEAT-UP ESTIMATED

1. **Heat absorbed by:** PANEL COIL AL. MOLD INSERTS

Weight of Material (Lb) x Specific Heat (BTU/Lb-F) x Temp. Dif. (Final-Initial) (F) / **3412(BTU/KWH) x (Time in Hours)** ______ KWH

2. **Heat absorbed by:** PANEL COIL - STEEL

$\frac{223 \text{ LBS.} \times .12 \times 200°F \times 30 \text{ MIN.}}{3412 \times .5}$ 3.14 KWH

3. **Heat absorbed by:** AL. INSERTS

$\frac{178 \text{ LBS.} \times .23 \times 200°F \times 30 \text{ MIN.}}{3412 \times .5}$ 4.8 KWH

4. **Heat absorbed by:** 3/8 FACE PLATE - AL. AL.

$\frac{75 \text{ LBS.} \times .23 \times 200°F \times 30 \text{ MIN.}}{3412 \times .5}$ 2.02 KWH

5. **Heat absorbed by:** TAIL ROTOR BLADES

$\frac{3.4 \text{ LBS.} \times .197 \times 200°F \times 30 \text{ MIN.}}{3412}$ .08 KWH

6. **Heat absorbed by:** ______

______ x ______ x ______ ______ KWH

Total Heat Requirement for Initial Heat-up: ______ KWH

Total Power Requirement for Initial Heat-up: ______ KWH

B. POWER REQUIREMENT FOR OPERATING HEAT

1. **Heat Required to Replace Heat Losses:**

(Exposed Surf. Area) (sq. ft) x (Heat Loss at Final Oper. Temp) (W/sq ft) x (Cycle Time) Hrs) / **1000 (W/KW)** ______ KWH

2. **Heat Required to Replace Heat Losses:** PANEL COIL - STEEL

$\frac{1.33 \text{ SQ. FT.} \times .180 \text{ WATTS/SQ. FT.} \times 1 \text{ HR}}{1000}$ .239 KWH

3. **Heat Required to Replace Heat Losses:** AL. FACE PLATES

$\frac{.88 \text{ SQ. FT.} \times 90 \text{ WATTS SQ. FT.} \times 1 \text{ HR}}{1000}$ .08 KWH

4. **Heat Required to Replace Heat Losses:** AL. MOLD INSERT

$\frac{3.17 \text{ SQ. FT.} \times 90 \text{ WATTS SQ. FT.} \times 1 \text{ HR.}}{1000}$ .285 KWH

Circulation Pump: 3.0 KWH

Total Energy Use 23.62 KWH

A. POWER REQUIREMENT FOR INITIAL HEAT-UP ACTUAL

1. Heat absorbed by: COMPLETE CURE CYCLE (PANEL COIL - AL. INSERT)

$$\frac{\text{Weight of Material (Lb)} \times \text{Specific Heat (BTU/Lb-F)} \times \text{Temp. Dif. (Final-Initial) (F)}}{3412\text{(BTU/KWH)} \times \text{(Time in Hours)}}$$ ______ KWH

2. Heat absorbed by: WATER

$$\frac{10.2\text{ GAL. } 85.068\text{ LB.} \times 1.0 \times 200°F \times 30\text{ MIN.}}{3412 \times .5}$$ 9.98 KWH

3. Heat absorbed by: WATER TO RAISE PARTS TO TEMP.

$$\frac{95.068\text{ LB/MIN} \times 1.0 \times 20°F \times 30\text{ MIN.}}{3412 \times .5}$$ 7.48 KWH

4. Heat absorbed by: WATER TO MAINTAIN OPERATING TEMP (CURE)

$$\frac{85.068\text{ LB/MIN} \times 1.0 \times 1°F \times 60\text{ MIN.}}{3412 \times .5}$$ 1.5 KWH

5. Heat absorbed by: ______

$$\frac{\_\_\_ \times \_\_\_ \times \_\_\_}{3412}$$ ______ KWH

6. Heat absorbed by: ______

______ x ______ x ______ ______ KWH

Total Heat Requirement for Initial Heat-up: ______ ______ KWH

Total Power Requirement for Initial Heat-up: ______ 18.96 KWH

B. POWER REQUIREMENT FOR OPERATING HEAT

1. Heat Required to Replace Heat Losses: ______

$$\frac{\text{(Exposed Surf. Area) (sq. ft)} \times \text{(Heat Loss at Final Oper. Temp) (W/sq ft)} \times \text{(Cycle Time) Hrs)}}{1000\text{ (W/KW)}}$$ ______ KWH

2. Heat Required to Replace Heat Losses: ______

$$\frac{\_\_\_}{1000}$$ ______ KWH

3. Heat Required to Replace Heat Losses: ______

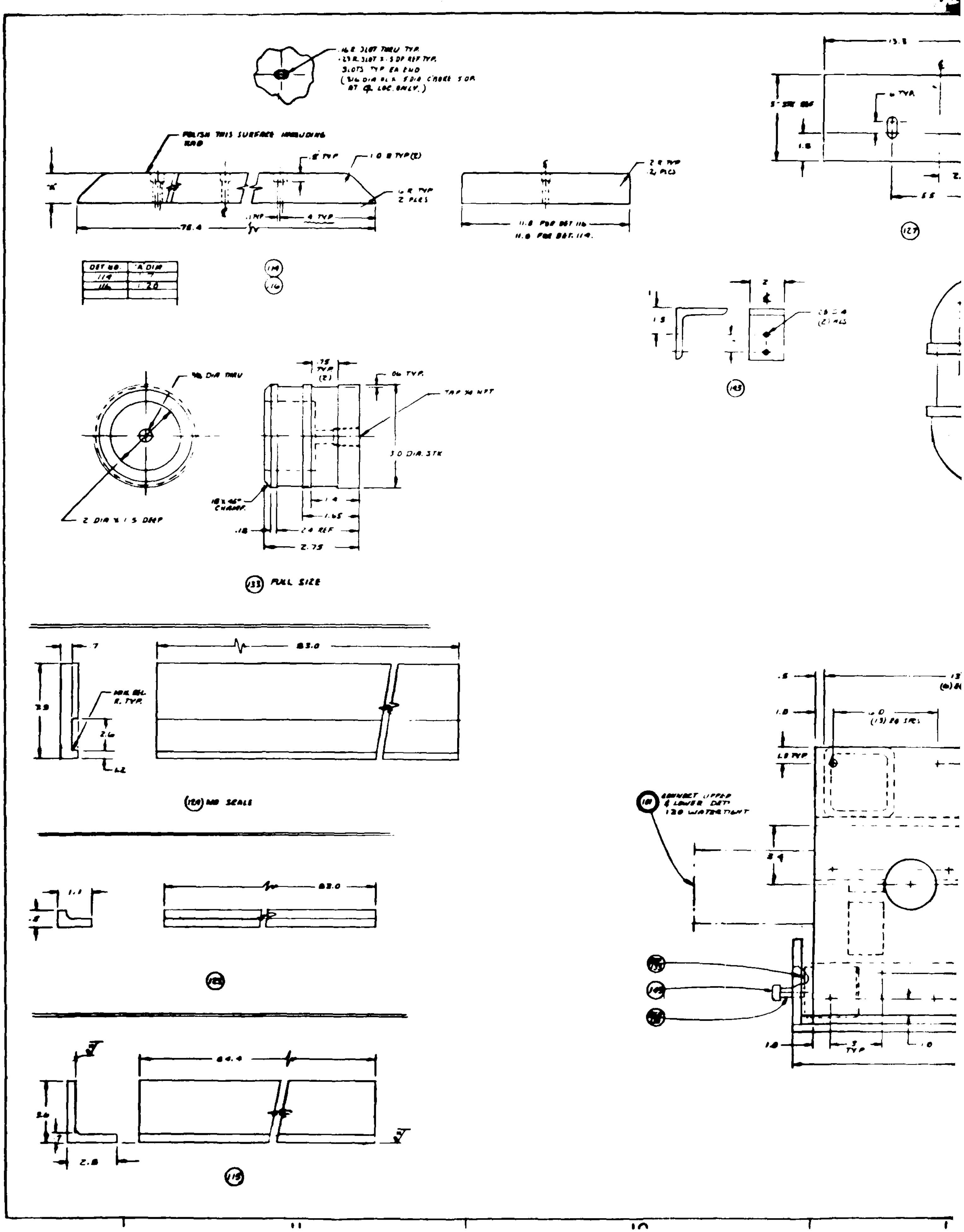
$$\frac{\_\_\_}{1000}$$ ______ KWH

4. Heat Required to Replace Heat Losses: ______

$$\frac{\_\_\_}{1000}$$ ______ KWH

Circulation Pump: .75 KWH

Total Energy Use 19.71 KWH



POLISH THIS SURFACE INCLUDING RAD
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11.6 FOR DET 114
DET NO.
A DIA
114
116
1.20
3/4 DIA THRU
TAP 3/4 NPT
3.0 DIA. STK
2 DIA X 1.5 DEEP
1.4
1.65
2.4 REF
2.75
.18
FULL SIZE
83.0
NO SCALE
83.0
64.4
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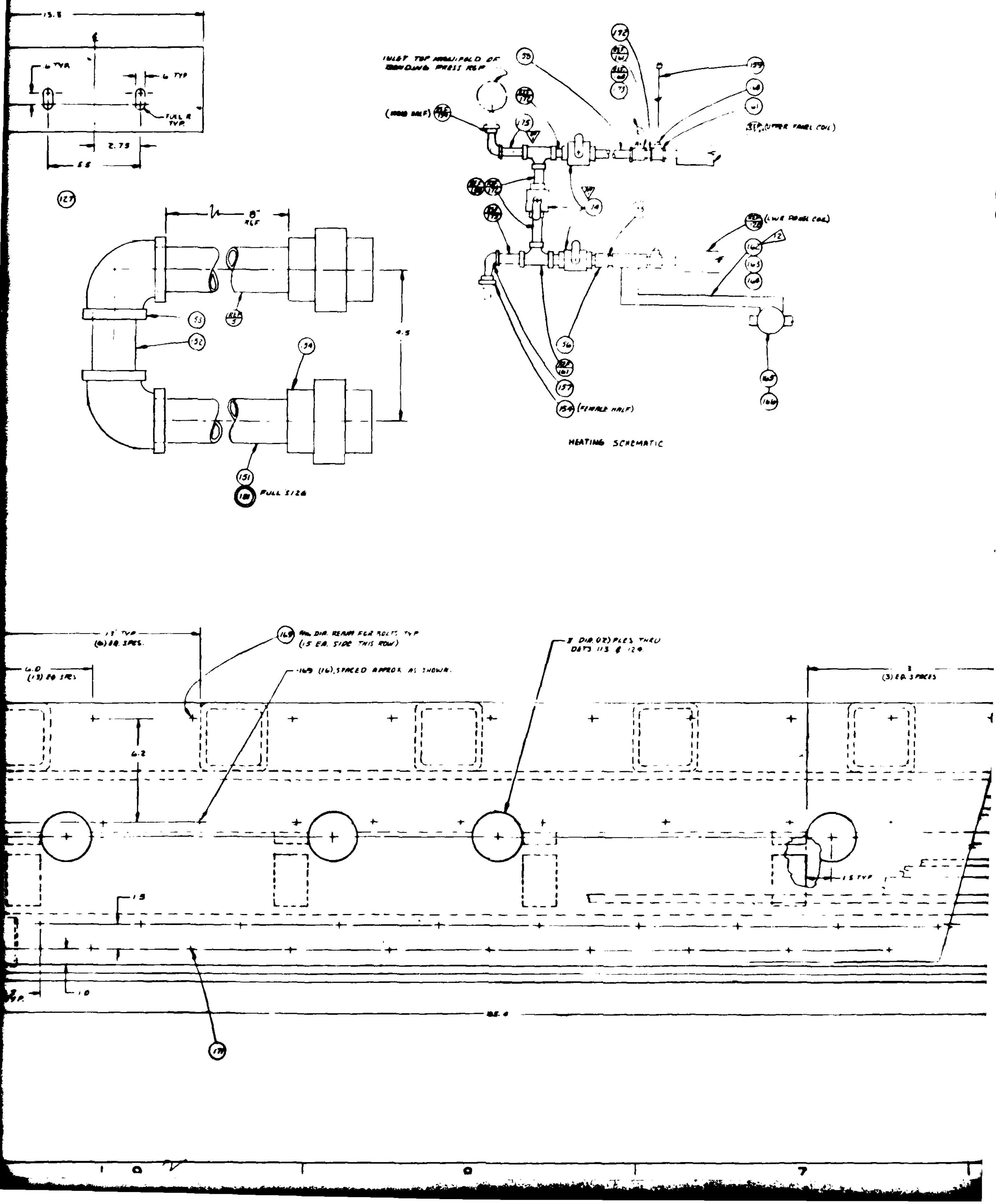
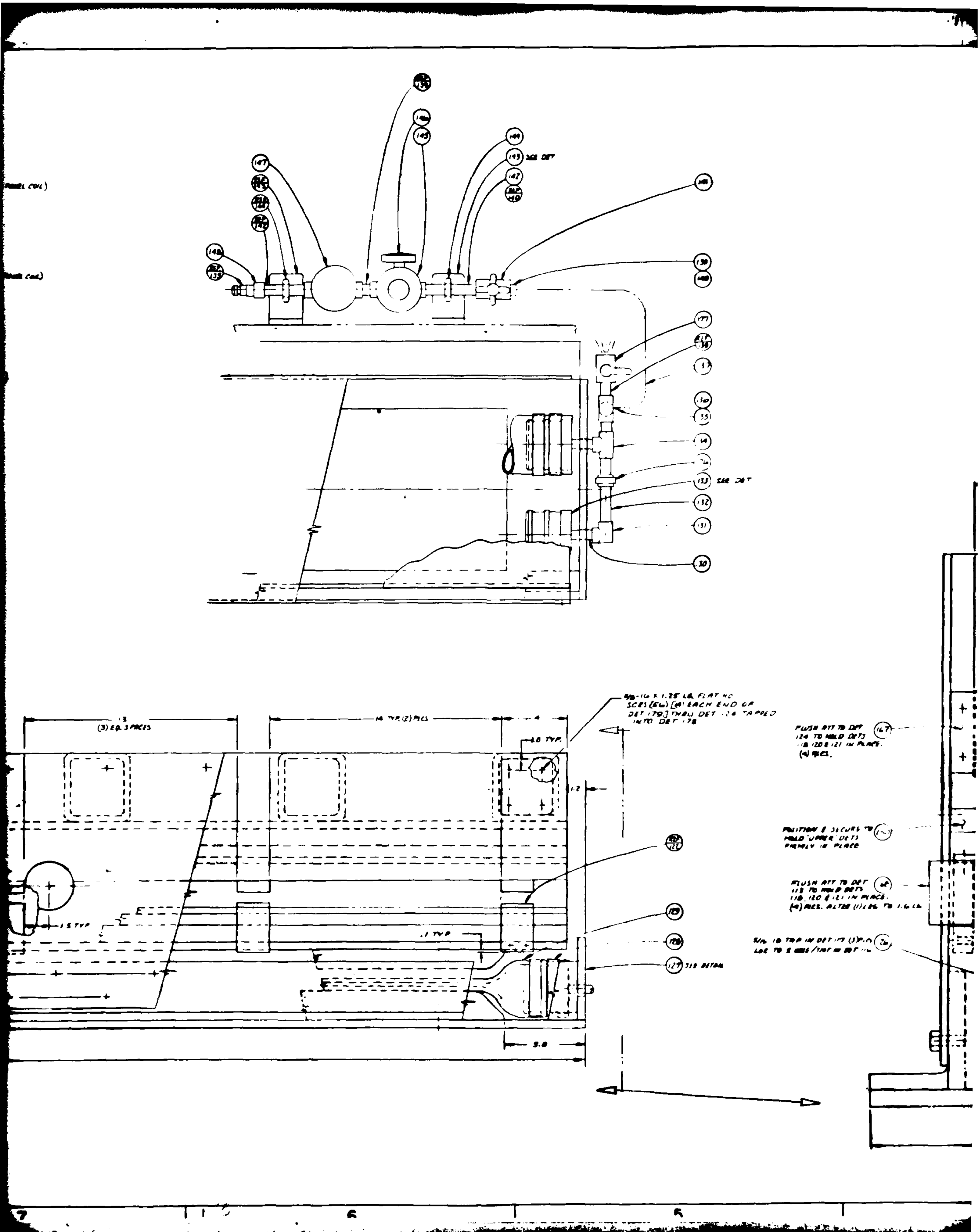
CONNECT UPPER & LOWER DET 120 WATERTIGHT



HEATING SCHEMATIC
FULL SIZE



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133 SEE DET
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(3) EQ. SPACES
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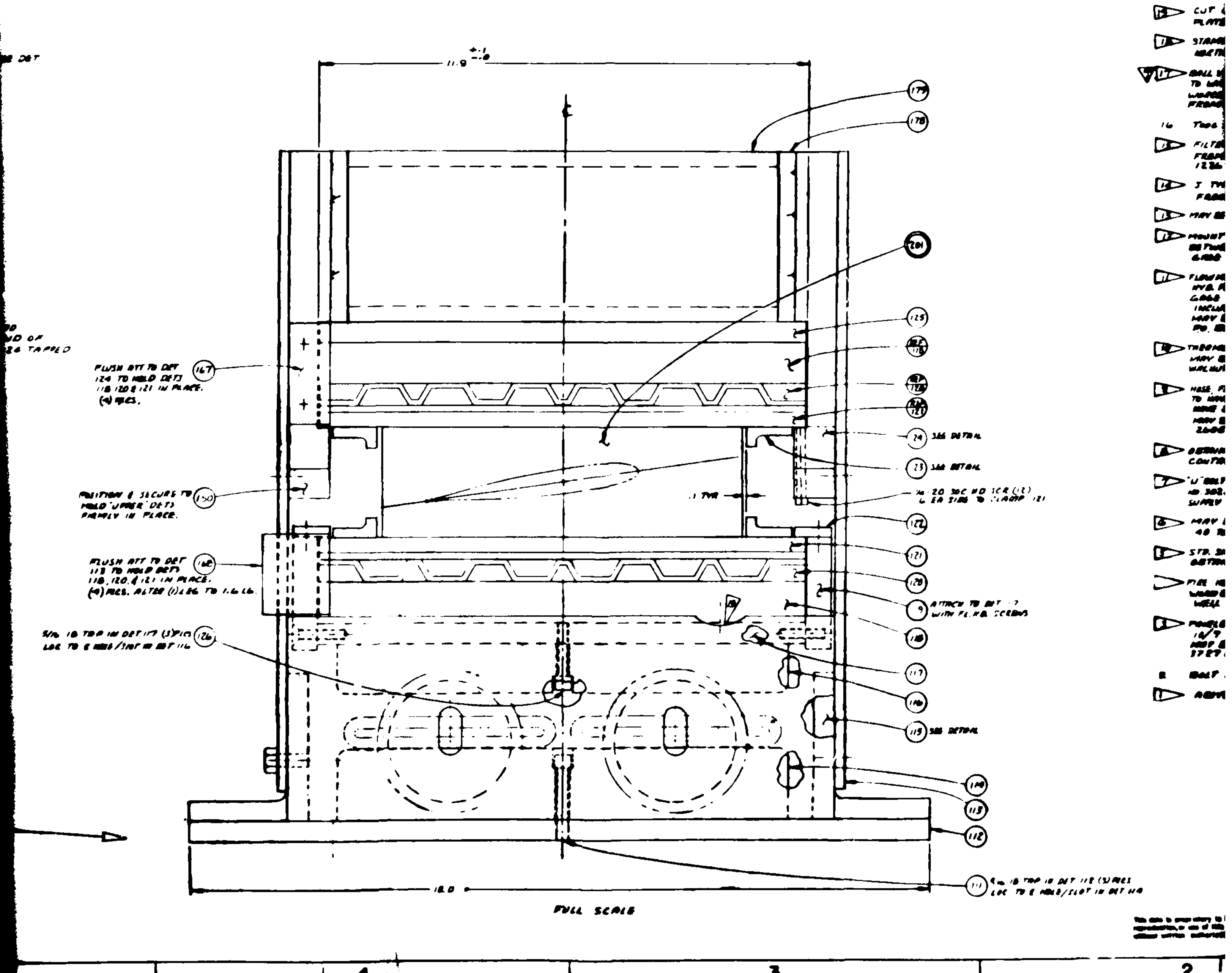
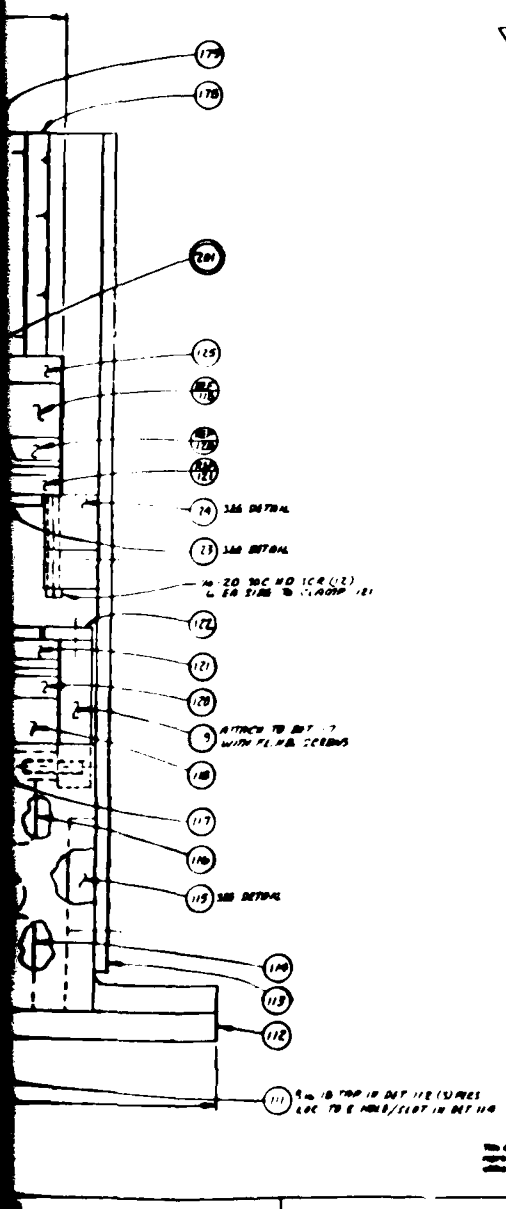
1.2
.1 TYP.
1.5 TYP.
5.0
INTO DET 178
FLUSH ATT TO DET
124 TO HOLD DETS
118 120 & 121 IN PLACE.
(4) PCS.
167
POSITION & SECURE TO
HOLD UPPER DETS
FIRMLY IN PLACE
FLUSH ATT TO DET
118, 120 & 121 IN PLACE.
129
128
127 SEE DETAIL
7
6
5

Appendi


11.9
179
178
201
125
167
FLUSH ATT TO DET 124 TO HOLD DETS 118,120 & 121 IN PLACE. (4) PCS.
150
POSITION & SECURE TO HOLD 'UPPER' DETS FIRMLY IN PLACE.
24 SEE DETAIL
23 SEE DETAIL
.1 TYP
1/4-20 SOC HD SCR (12) 6 EA SIDE TO CLAMP 121
122
121
120
168
FLUSH ATT TO DET 113 TO HOLD DETS 118,120,& 121 IN PLACE. (4) PCS. ALTER (1) LEG TO 1.6 LG.
9 ATTACH TO DET 117 WITH FL.HD. SCREWS
118
126
117
116
115 SEE DETAIL
114
113
112
111
12.0
FULL SCALE

4
3
2

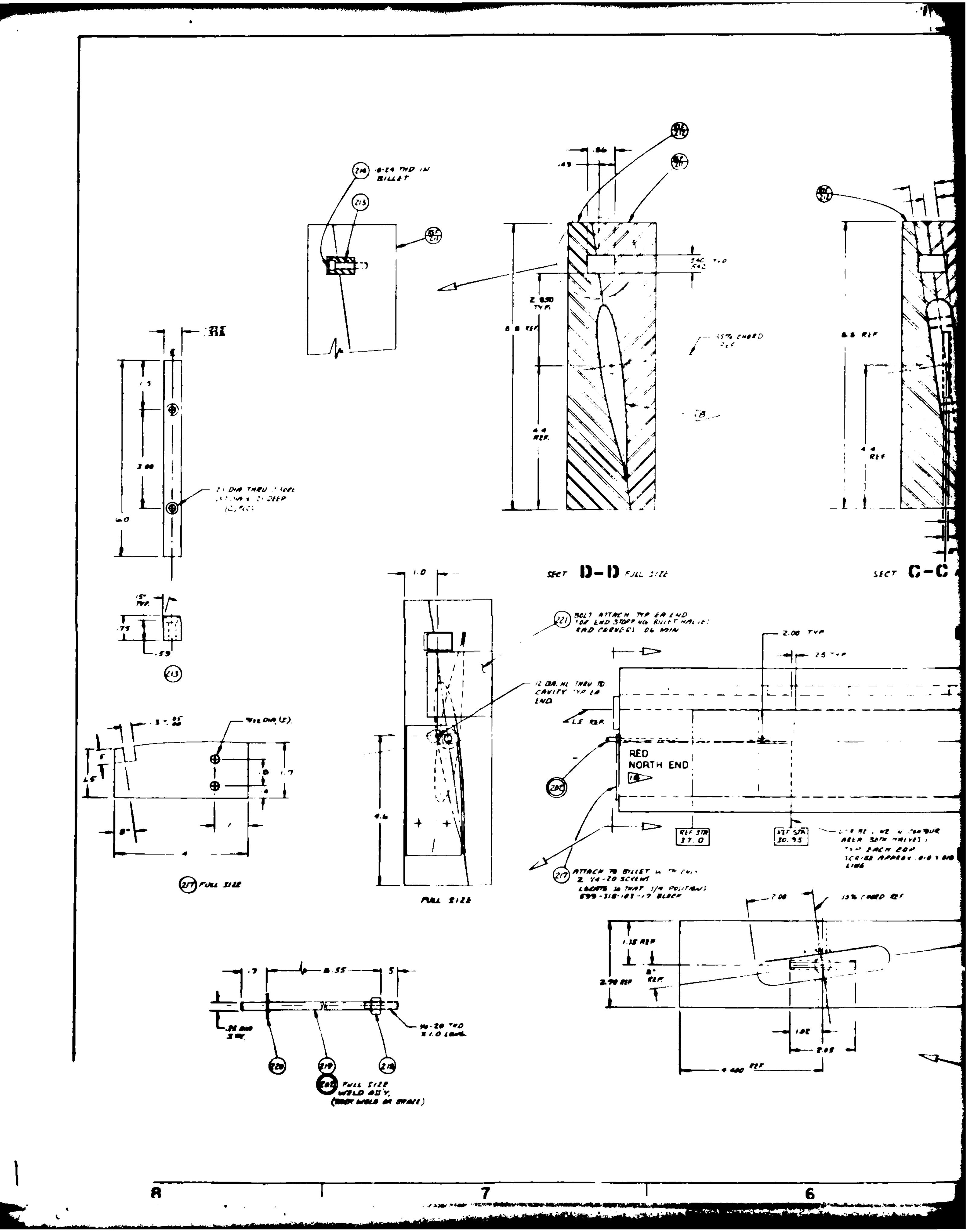
Appendix B

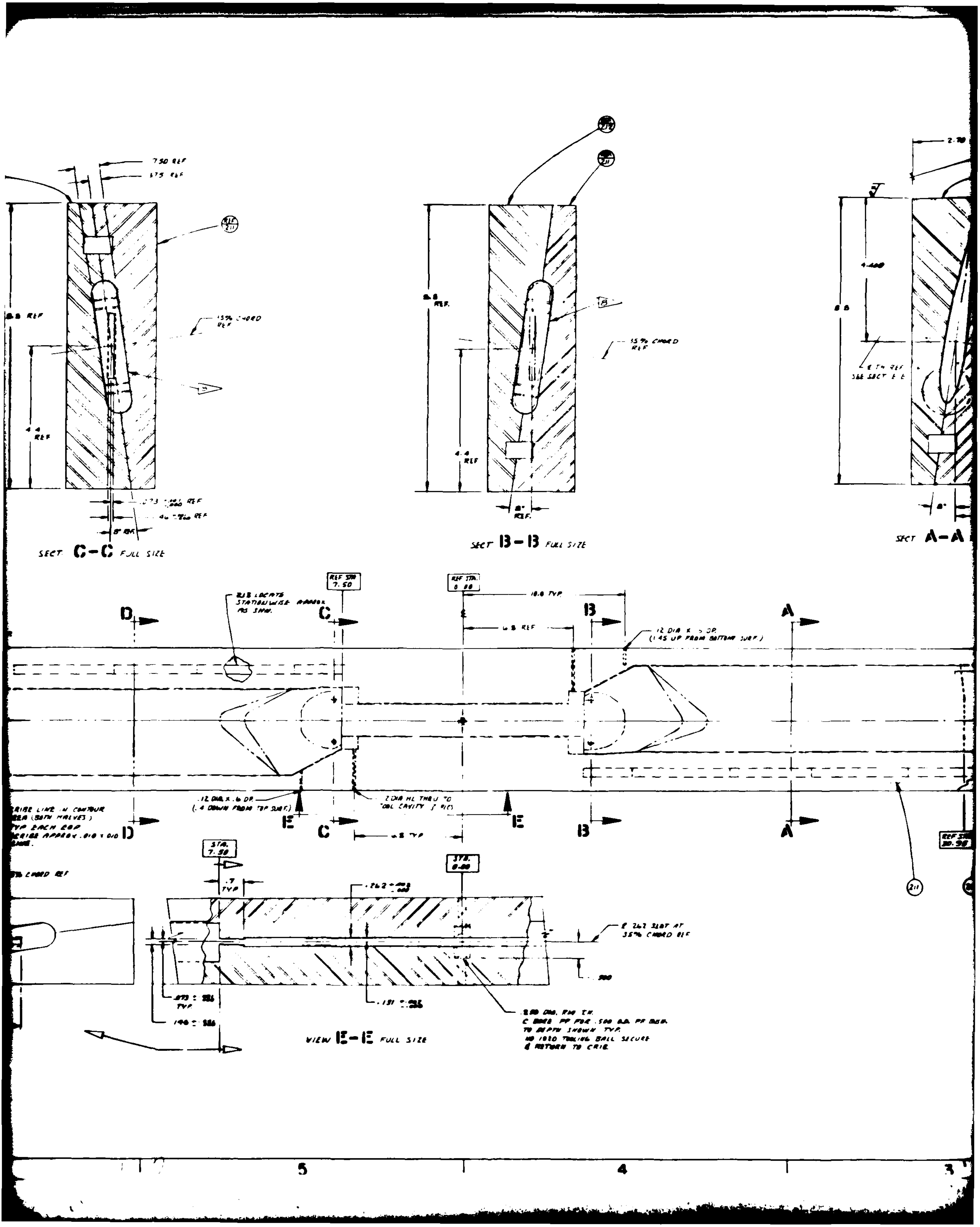


- CUT CLEARANCE APPROX AS SHOWN IN EACH END PLATE TO CLEAR PANEL COIL PLUMBING
- STAMP WITH HALF INCH HIGH LETTERS NORTH END & FILL WITH RED PAINT
- BALL VALVE FULL PORT QUARTER TURN 1" FEMALE PIPE THD TO WITHSTAND 400°F WATER STEAM AT 400 PSI WORCESTER NO 5911 PV SE OR EQUIV MAY BE PURCH FROM MARVELL-WILDER
- 16 TOOL MPE TO FURNISH TABLE ATT J WASSON.
- FILTER REGULATOR & GAGES MAY BE PURCHASED FROM WOMACK MACHINE SUPPLY CO CAT NO 1226 SO MAIN FT WORTH TEX 76104.
- J TYPE THERMOCOUPLE WIRE MAY BE OBTAINED FROM MAINTENANCE
- MAY BE OBTAINED FROM JOHN MANVILLE CO.
- MOUNT FLOWMETER GAGE WITH 20 FT CA DET BETWEEN GAGE & FLOWMETER TO REDUCE HEAT AT GAGE TO 200°F OR LESS PERMISSABLE TO COIL TUBE
- FLOWMETER NO VSN 602 ... (MOD) OR EQUIV HYD FLOWMETER FOR INLINE ... IN 1" PIPE WITH GAGE CALIBRATED & MODIFIED TO READ 0 TO ... GPM INCLUDE BRACKET FOR WALL MOUNTING GAGE MAY BE PURCHASED FROM FLOW-DYNE ENG INC PO BOX 9034 FT WORTH TEX 732 2858
- THERMOCOUPLE NO ... OR EQUIV MAY BE PURCHASED FROM THERMO ELECTRIC ... WALNUT HILL LANE SUITE ... DALLAS TEX
- HOSE FLEX TO WITHSTAND 400°F TEMP WATER AT 400 PSI TO HAVE MALE PIPE THD EACH END (ONE END MAY HAVE SWIVEL ADAPTER PROVIDED ... MAINTAINED) MAY BE PURCHASED FROM ... INTERNATIONAL 2406 WHITE SETTLEMENT RD FT WORTH TEX
- OBTAIN CONTOUR FROM EXISTING BLADE ... CONTACT J.M GOODWIN DEPT 83 EXT 2445
- "U" BOLT ... THD LENGTH ... THD DIA ... BETWEEN LEGS NO 302. MAY BE PURCHASED FROM CENTRAL INDUSTRIAL SUPPLY CO 2325 W JEFFERSON GRAND PRAIRIE TEX.
- MAY BE OBTAINED FROM SURPLUS FROM DEPT 40 TOOL & DIE HURST.
- STD SHOP AIR HOSE FITTINGS & CONNECTORS MAY BE OBTAINED FROM MAINTENANCE STORES 69
- FIRE HOSE 1" DIA DOUBLE JACKET AND ... RATED ... MAY BE PURCHASED FROM ... WELL MACHINERY PO BOX ... FT WORTH TEXAS
- PANELCOIL 12 X 83 ... TANGENTIAL FLOW 16/7 CRS MAT'L ... MAY BE PURCHASED FROM ... INCORPORATED 3727 ... RD SUITE 5C DALLAS TEX 75220
- 2 BOLT & DOWEL CONSTRUCTION TO SUIT.
- ABOVE QUANTITY TOTAL REQD PER TOOL

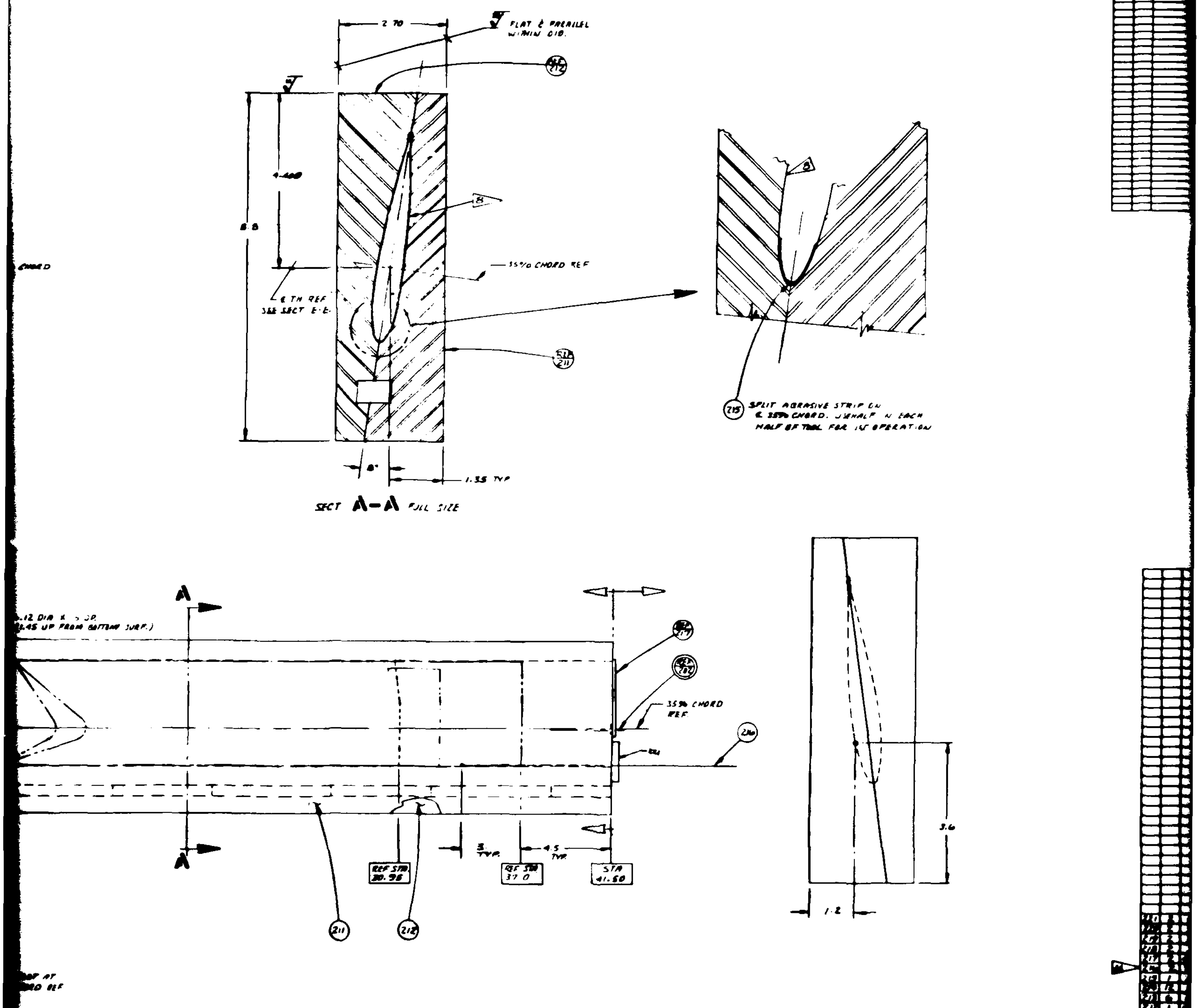
GENERAL NOTES

TO MOLD T/R BLADE

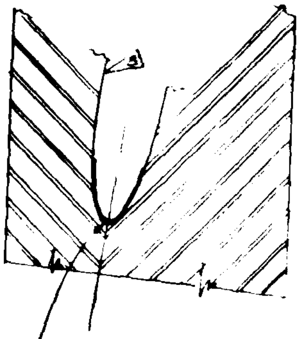

10-24 THD IN BILLET
SECT D-D FULL SIZE
SECT C-C
BOLT ATTACH TYP EA END
12 DIA. HL THRU TO CAVITY TYP EA END
LE REF.
RED
NORTH END
REF STA 37.0
REF STA 30.95
35% CHORD REF
FULL SIZE
FULL SIZE
1/4-20 THD X 1.0 LONG
FULL SIZE
WELD ASSY.
8
7
6



SECT C-C FULL SIZE
SECT B-B FULL SIZE
SECT A-A
15% CHORD REF
8.8 REF
4.4 REF
8° REF
REF STA 7.50
REF STA 0.00
10.0 TYP
6.8 REF
.12 DIA X .5 DP (1.45 UP FROM BOTTOM SURF.)
.12 DIA X .6 DP (.4 DOWN FROM TOP SURF.)
.2 DIA HL THRU TO TOOL CAVITY 2 PLCS
STA. 7.50
STA. 0.00
.7 TYP
VIEW E-E FULL SIZE
.500
5
4
3

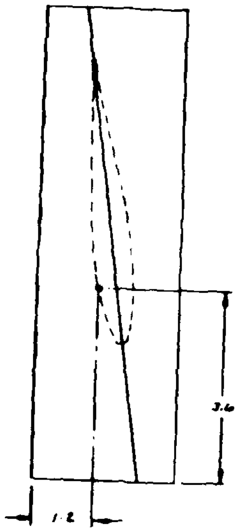

2.70
FLAT & PARALLEL WITHIN .010
REF 212
4.400
8.8
B
35% CHORD REF
℄ TH REF SEE SECT E-E
REF 211
.8°
1.35 TYP
SECT A-A FULL SIZE
215 SPLIT ABRASIVE STRIP ON ℄ 35% CHORD. USE HALF IN EACH HALF OF TOOL FOR 1ST OPERATION
A
.12 DIA X .5 DP (.45 UP FROM BOTTOM SURF.)
35% CHORD REF
REF STA 30.96
REF STA 37.0
STA 41.50
3 TYP
4.5 TYP
211
212
3.6
1.2

W



(215) SPLIT ABRASIVE STRIP C.L.
& 25% CHORD. USE HALF ... EACH
HALF OF TOOL FOR ... OPERATION

X



Y

221	2	CRS	1/4 x 2 x 2 C	[illegible]
220	2	STD	[illegible]	[illegible]
219	2	CRS	1/4 DIA x 9 [illegible]	[illegible]
218	2	STD	[illegible] 2C	[illegible]
217	2	[illegible]	[illegible]	[illegible]
216	2	THERMOCOUPLE	[illegible]	[illegible]
215	1	A/O	[illegible]	[illegible]
214	12	STD	1/4-20 x [illegible]	[illegible]
213	6	CRS	[illegible]	[illegible]
212	1	ALUM	2 x 18 x [illegible]	[illegible]
211	1	ALUM	2 x [illegible]	[illegible] - T6

Z

202	2	WAY DET. 2-02-94 220	
201	1	S/A OF DETS [illegible]	

SEE SHT. 1

[illegible] SYSTEM
[illegible] TAIL ROTOR
[illegible] DEV 191

2

1

Appendix C

MOLD SYSTEM SAFETY RATINGS

PANEL COIL	-	ASME CODE PRESSURE RATING TESTED AT 591 PSI
CIRCULATING HEATERS	-	ASME CODE PRESSURE RATING WATER TIGHT ELECTRICALS
HEAT EXCHANGER	-	DESIGNED FOR 400 PSI WORKING PRESSURE
FLOW METER	-	5,000 PSI MAXIMUM PRESSURE
HEAVY DUTY PIPE	-	2,500 PSI MAXIMUM PRESSURE INSULATED/SAFE TO THE TOUCH
FLEXIBLE HOT WATER LINES	-	1,000 PSI MAXIMUM WORKING PRESSURE 4,000 PSI MINIMUM BURST PRESSURE
FLEXIBLE AIRLINES	-	300 PSI MINIMUM BURST PRESSURE

Appendix D

Bell Helicopter TEXTRON
Division of Textron Inc

POST OFFICE BOX 482 · FORT WORTH TEXAS 76101

PART No 599-318-103

KBXKK Blade No. 1A

R.R. No

REPORT No [illegible]

DATE [illegible]

TESTED BY [illegible]

APPROVED R. Anderson
R. ANDERSON

APPROVED [illegible]

COPIES TO:

B. Anderson
J. Baker
J. Peach
R. Sadler
Lab Files

LABORATORY REPORT

TITLE Destructive Test

ITEM Bearingless Tail Rotor Blade

SPEC No 599-318-103

VENDOR BHT

Destructive test on the 599-318-103 bearingless tail rotor blade No. 1A has been accomplished by the Methods and Materials Laboratory in accordance with the test plan incorporated as page 2 of this report.

Quantitative and qualitative analyses were conducted on the tip cut-off sample of both the "white" and the "red" blade (Sta. 30.95 to Sta. 37.0) to determine if voids or other discrepancies exist in the bondlines. This was the second blade produced in the new integrally heated and pressurized mold tool.

1. No discrepancies noted during qualitative evaluation (Test Section VI).
2. Quantitative test results are recorded on attached sheets of this report.

7872 55418

AD-A102 743 BELL HELICOPTER TEXTRON FORT WORTH TX F/6 1/3
FABRICATION AND DEMONSTRATION OF AN INTEGRALLY HEATED AND PRESS--ETC(U)
MAR 81 R G ANDERSON, E E BLAKE DAAG46-79-C-0032
UNCLASSIFIED USAAVRADCOM-TR-81-F-11 NL

2 OF 2
AD A
102743

END
DATE
FILMED
9-81
DTIC

Bell Helicopter TEXTRON
Division of Textron Inc
POST OFFICE BOX 482 • FORT WORTH, TEXAS 76101

Material
Type N1113 Adhesive
Batch
Roll
Primer
Batch

599-318-103

LABORATORY REPORT
ADHESIVES AND PLASTICS

REPORT DT80-34A
DATE 3-7-80
PREPARED BY J. Peckham
TESTED BY J. Peckham
APPROVED [handwritten initials]

Copies to:

TITLE Destructive Test
TYPE TEST
REF. N. B. PAGE

Blade No. 1A - white

Average
High
Low

Bonding Condition
Time
Temp °F
psi
Material
Preparation
Date

IDENTIFICATION	LENGTH	WIDTH	AREA	LOAD	BONDLINE THICKNESS	TYPE FAILURE	STRENGTH (PSI) (PLI)	REMARKS
I	.263	.268	.070	240		Adhes.	3428	
II Top	.270	.497	.134	170		Block	1268	
II Bot	.289	.502	.145	200		Block	1379	
III Top	.247	.483	.119	300		Glass	2521	
III Bot	.251	.493	.123	280		Glass	2276	
IV Top	.249	.463	.115	400		Glass	3478	
IV Bot	.229	.435	.099	400		Glass	4040	
V Top	--	--	--	--		--	24.62 percent	
V Bot	--	--	--	--		--	25.00 percent	
VI	ACCEPTABLE							

7872 59418

Bell Helicopter TEXTRON

Division of Textron Inc

POST OFFICE BOX 482 • FORT WORTH, TEXAS 76101

Material

Type N1113 Adhesive

Batch

Roll

Primer

Batch

599-318-103

LABORATORY REPORT
ADHESIVES AND PLASTICS

REPORT DT80-34A

DATE 3-7-80

PREPARED BY J. Peckham

TESTED BY J. Peckham

APPROVED Kr

Copies to:

TITLE Destructive Test

TYPE TEST

REF. N. B. PAGE

Blade No. 1A - Red

Average

High

Low

Bonding Condition

Time

Temp °F

psi

Material

Preparation

Date

IDENTIFICATION	LENGTH	WIDTH	AREA	LOAD	BONDLINE THICKNESS	TYPE FAILURE	STRENGTH (PSI) (PLI)	REMARKS
I	.220	.267	.058	150		Cohes.	2586	
II Top	.278	.491	.136	240		Adhes.	1764	
II Bot	.281	.485	.136	260		Block	1913	
III Top	.229	.497	.113	220		Glass	1946	
III Bot	.285	.493	.140	280		Glass	2000	
IV Top	.229	.437	.100	180		Glass	1800	
IV Bot	.233	.458	.106	240		Glass	2264	
V Top	--	--	--	--		--	27.69 PERCENT	
V Bot	--	--	--	--		--	26.47 PERCENT	
VI		ACCEPTABLE						

Bell Helicopter TEXTRON
Division of Textron Inc.

POST OFFICE BOX 482 • FORT WORTH, TEXAS 76101

PART No. 599-318-103

~~XXXX~~ Blade No. 2

R R No.

REPORT No. DT80-[illegible]4B

DATE 3-7-80

TESTED BY J. Peckham

APPROVED K. Anderson

APPROVED J. Cernosek

LABORATORY REPORT

COPIES TO

B. Anderson
J. Baker
J. Peach
R. Sadler
Lab Files

TITLE Destructive Test

ITEM Bearingless Tail Rotor Blade

SPEC No. 599-318-103

VENDOR BHT

Destructive test on the 599-318-103 bearingless tail rotor blade No. 2 has been accomplished by the Methods and Materials Laboratory in accordance with the test plan incorporated as page 2 of this report.

Quantitative and qualitative analyses were conducted on the tip cut-off sample of both the "white" and the "red" blade (Sta. 30.95 to Sta. 37.0) to determine if voids or other discrepancies exist in the bondlines. This was the third blade produced in the new integrally heated and pressurized mold.

1. No discrepancies noted during qualitative evaluation (Test Section VI).
2. Quantitative test results are recorded on attached sheets of this report.

7872 55418

Bell Helicopter TEXTRON

Division of Textron Inc.

Post Office Box 482 • Fort Worth, Texas 76101

599-318-103

LABORATORY REPORT
ADHESIVES AND PLASTICS

REPORT DT80-34B
DATE 3-7-80
PREPARED BY J. Peckham
TESTED BY J. Peckham
APPROVED

Material
Type N1113 Adhesive
Batch
Roll
Primer
Batch

Copies to:

TITLE Destructive Test

TYPE TEST

REF. N. B. PAGE

Blade No. 2 - White

Average
High
Low

Bonding Condition
Time
Temp °F
psi
Material
Preparation
Date

IDENTIFICATION	LENGTH	WIDTH	AREA	LOAD	BONDLINE THICKNESS	TYPE FAILURE	STRENGTH (PSI) (PLI)	REMARKS
I	.220	.307	.068	100		Glass	1470	See Retest
II Top	.300	.462	.139	200		Block	1438	
II Bot	.308	.461	.142	240		Block	1690	
III Top	.240	.470	.113	200		Glass	1769	
III Bot	.275	.475	.131	240		Glass	1832	
IV Top	.233	.413	.096	300		Glass	3125	
IV Bot	.271	.428	.116	60		Adhes.	517	See Retest
V Top	--	--	--	--		--	26.09 PERCENT	
V Bot	--	--	--	--		--	26.58 PERCENT	
VI	ACCEPTANCE							
I RETEST	.213	.268	.057	60		Glass	1052	
I RETEST	.272	.287	.078	60		Glass	769	
IV Bot-RETEST	.277	.430	.119	60		Adhes.	504	
IV Bot-RETEST	.225	.421	.095	80		Adhes.	842	

Bell Helicopter TEXTRON
Division of Textron Inc
POST OFFICE BOX 482 • FORT WORTH, TEXAS 76101

PART No 599-318-103
REPORT No DT80-34B
KXXKK Blade No. 2
DATE 3-7-80
R R No
TESTED BY J. Peckham
COPIES TO
LABORATORY REPORT
APPROVED K. Anderson
APPROVED J. Cermosek

B. Anderson
J. Baker
J. Peach
R. Sadler
Lab Files

TITLE Destructive Test
ITEM Bearingless Tail Rotor Blade
SPEC No 599-318-103
VENDOR BHT

Destructive test on the 599-318-103 bearingless tail rotor blade No. 2 has been accomplished by the Methods and Materials Laboratory in accordance with the test plan incorporated as page 2 of this report.

Quantitative and qualitative analyses were conducted on the tip cut-off sample of both the "white" and the "red" blade (Sta. 30.95 to Sta. 37.0) to determine if voids or other discrepancies exist in the bondlines. This was the third blade produced in the new integrally heated and pressurized mold.

1. No discrepancies noted during qualitative evaluation (Test Section VI).
2. Quantitative test results are recorded on attached sheets of this report.

7872 55418

Bell Helicopter TEXTRON
Division of Textron Inc.
POST OFFICE BOX 482 • FORT WORTH, TEXAS 76101

Material
Type N1113 Adhesive
Batch
Roll
Primer
Batch

599-318-103

LABORATORY REPORT
ADHESIVES AND PLASTICS

REPORT DT80-34B
DATE 3-7-80
PREPARED BY J. Peckham
TESTED BY J. Peckham
APPROVED

Copies to:

TITLE Destructive Test

TYPE TEST

REF. N. B. PAGE

Blade No. 2 - White

Bonding Condition
Time
Temp °F
psi
Material
Preparation
Date

Average
High
Low

IDENTIFICATION	LENGTH	WIDTH	AREA	LOAD	BONDLINE THICKNESS	TYPE FAILURE	STRENGTH IPSI (PLI)	REMARKS
I	.220	.307	.068	100		Glass	1470	See Retest
II Top	.300	.462	.139	200		Block	1438	
II Bot	.308	.461	.142	240		Block	1690	
III Top	.240	.470	.113	200		Glass	1769	
III Bot	.275	.475	.131	240		Glass	1832	
IV Top	.233	.413	.096	300		Glass	3125	
IV Bot	.271	.428	.116	60		Adhes.	517	See Retest
V Top	--	--	--	--		--	26.09 PERCENT	
V Bot	--	--	--	--		--	26.58 PERCENT	
VI	ACCEPTANCE							
I RETEST	.213	.268	.057	60		Glass	1052	
I RETEST	.272	.287	.078	60		Glass	769	
IV Bot-RETEST	.277	.430	.119	60		Adhes.	504	
IV Bot-RETEST	.225	.421	.095	80		Adhes.	842	

Bell Helicopter TEXTRON
Division of Textron Inc.

POST OFFICE BOX 482 • FORT WORTH, TEXAS 76101

Material 599-318-103 REPORT [illegible]80-34B

Type N1113 Adhesive DATE [illegible]-80

Batch

Roll

Primer

Batch

LABORATORY REPORT
ADHESIVES AND PLASTICS

PREPARED BY J. Peckham

TESTED BY J. Peckham

APPROVED Kg

Copies to:

TITLE Destructive Test

TYPE TEST

REF. N. B. PAGE

Blade No. 2 - Red

Average

High

Low

Bonding Condition

Time

Temp. °F

psi

Material

Preparation

Date

IDENTIFICATION	LENGTH	WIDTH	AREA	LOAD	BONDLINE THICKNESS	TYPE FAILURE	STRENGTH PSI [illegible]	REMARKS
I	.245	.288	.070	100		Glass	1428	See Retest
II Top	.294	.455	.134	230		Block	1716	
II Bot	.278	.466	.130	200		Block	1538	See Retest
III Top	.247	.460	.114	100		Glass	877	
III Bot	.285	.470	.134	310		Glass	2313	
IV Top	.247	.409	.101	140		Glass	1386	See Retest
IV Bot	.245	.421	.103	180		Adhes.	1747	See Retest
V Top	--	--	--	--		--	26.67 PERCENT	
V Bot	--	--	--	--		--	[illegible] PERCENT	
VI	ACCEPTABLE							
I RETEST	.218	.294	.064	60		Glass	[illegible]	
	.228	.291	.066	80		Glass	[illegible]	
III Top RETEST	.253	.441	.112	300		Glass	[illegible]	
	.278	.271	.075	130		Glass	1733	
IV Top RETEST	.280	.418	.117	300		Glass	[illegible]	
	.305	.425	.130	170		Glass	1307	
IV Bot RETEST	.220	.416	.092	120		Glass	[illegible]	
	.282	.424	.120	120		Glass	1000	

7072 55410

Bell Helicopter TEXTRON
Division of Textron Inc

POST OFFICE BOX 482 • FORT WORTH, TEXAS 76101

PART No 599-318-103

KXXXX Blade No. 3

R R No

REPORT No [illegible]

DATE [illegible]-7-80

TESTED BY J. Peckham

APPROVED R. Anderson

APPROVED J. Cernosek

COPIES TO

B. Anderson
J. Baker
J. Peach
R. Sadler
Lab Files

LABORATORY REPORT

TITLE Destructive Test

ITEM Bearingless Tail Rotor Blade

SPEC No 599-318-103

VENDOR BHT

Destructive test on the 599-318-103 bearingless tail rotor blade No. 3 has been accomplished by the Methods and Materials Laboratory in accordance with the test plan incorporated as page 2 of this report.

Quantitative and qualitative analyses were conducted on the tip cut-off sample of both the "white" and the "red" blade (Sta. 30.95 to Sta. 37.0) to determine if voids or other discrepancies exist in the bondlines. This was the fourth blade produced in the new integrally heated and pressurized mold.

1. No discrepancies noted during qualitative evaluation (Test Section VI).
2. Quantitative test results are recorded on attached sheets of this report.

7872 55418

Bell Helicopter TEXTRON
Division of Textron Inc
POST OFFICE BOX 482 • FORT WORTH TEXAS 76101

Material
Type N1113 Adhesive
Batch
Roll
Primer
Batch

599-318-103

LABORATORY REPORT
ADHESIVES AND PLASTICS

REPORT DT80-34C
DATE 3-7-80
PREPARED BY J. Peckham
TESTED BY J. Peckham
APPROVED

Copies to:

TITLE Destructive Test
TYPE TEST
REF. N. B. PAGE

Bonding Condition
Time
Temp. °F
psi
Material
Preparation
Date

Average
High
Low

Blade No. 3 - White

IDENTIFICATION	LENGTH	WIDTH	AREA	LOAD	BONDLINE THICKNESS	TYPE FAILURE	STRENGTH (PSI) (PLI)	REMARKS
I	.249	.301	.075	220		Glass	2933	
II Top	.277	.472	.131	190		Block	1450	
II Bot	.299	.458	.137	220		Block	1605	
III Top	.303	.465	.141	200		Glass	1418	See Retest
III Bot	.239	.472	.113	220		Glass	1946	
IV Top	.243	.455	.110	140		Glass	1272	See Retest
IV Bot	.266	.469	.125	300		Glass	2400	
V Top	--	--	--	--		--	23.26 PERCENT	
V Bot	--	--	--	--		--	19.23 PERCENT	
VI	ACCEPTABLE							
III Top RETEST	.260	.466	.121	240		Glass	1983	
III Top RETEST	.260	.489	.127	320		Glass	2519	
IV Top RETEST	.278	.455	.126	400		Cohes.	3174	
IV Top RETEST	.237	.457	.108	140		Glass	1296	

Bell Helicopter TEXTRON
Division of Textron Inc
POST OFFICE BOX 482 • FORT WORTH TEXAS 76101

Material
Type N1113 Adhesive
Batch
Roll
Primer
Batch

599-318-103

LABORATORY REPORT
ADHESIVES AND PLASTICS

REPORT DT80-34C
DATE 3-7-80
PREPARED BY J. Peckham
TESTED BY J. Peckham
APPROVED [signature]

Copies to:

TITLE Destructive Test
TYPE TEST
REF. N. B. PAGE
Blade No. 3 - Red

Bonding Condition
Time
Temp. °F
psi
Material
Preparation
Date

Average
High
Low

IDENTIFICATION	LENGTH	WIDTH	AREA	LOAD	BONDLINE THICKNESS	TYPE FAILURE	STRENGTH (PSI) (PLI)	REMARKS
1	.259	.302	.078	240		Glass	3076	
II Top	.263	.455	.120	200		Block	1666	
II Bot	.270	.468	.126	220		Block	1746	
III Top	.247	.448	.111	160		Glass	1441	See Retest
III Bot	.275	.466	.128	200		Glass	1562	See Retest
IV Top	.265	.456	.121	480		Glass	3966	
IV Bot	.245	.455	.111	450		Cohes.	4054	
V Top	--	--	--	--		--	26.67 PERCENT	
V Bot	--	--	--	--		--	24.44 PERCENT	
VI	ACCEPTABLE							
III Top RETEST	.305	.479	.146	260		Glass	1780	
III Top RETEST	.275	.475	.131	220		Glass	1679	
III Bot RETEST	.277	.517	.143	320		Glass	2237	
III Bot RETEST	.281	.475	.133	300		Glass	2255	

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